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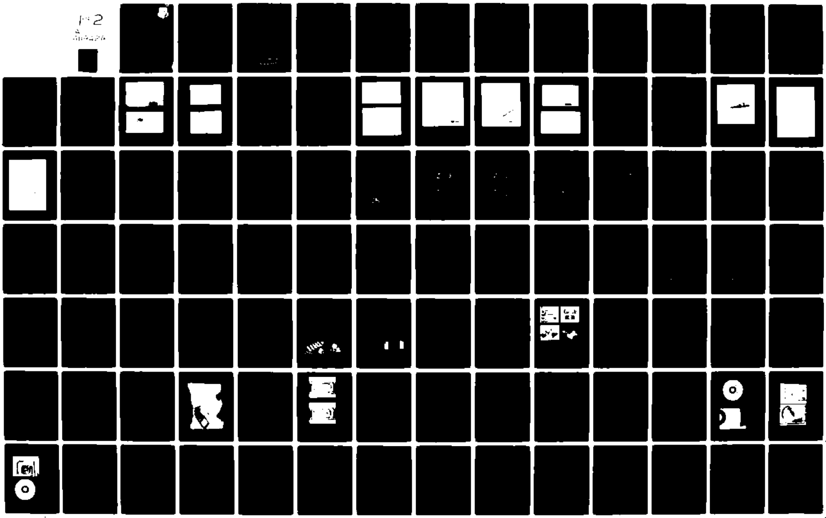

AFWAL-TR-82-2048

LIQUID COOLED VARIABLE SPEED CONSTANT FREQUENCY (VSCF) CONVERTER DEVICE DEVELOPMENT

GENERAL ELECTRIC COMPANY
P.O. BOX 5000
BINGHAMTON, NEW YORK 13902

JUNE 1982

FINAL REPORT FOR PERIOD SEPTEMBER 1978 TO DECEMBER 1981

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

William U. Borger

Wm. U. Borger
Project Engineer

Paul R. Bertheaud

Paul R. Bertheaud
Technical Area Manager
Power Systems Branch

FOR THE COMMANDER

J. D. Reams

James D. Reams
Chief, Aerospace Power Division

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Further miniaturization of high-power semi-conductor devices utilizing silicon disks larger than 12 mm. requires major innovations to improve the average thermal impedance and surge capability. The high thermal impedance in existing discrete devices is caused mostly by the dry interfaces necessary to provide stress relief.

This report presents a unique approach to solving the dry interface problem. It describes the design, fabrication and evaluation of a smaller, lighter, electrically isolated dual thyristor module featuring structured copper, solder bonding, polyimide passivation, direct bonded copper on beryllium oxide and a hermetic sealed aluminum case. → cont

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cont

Details of the SCR modules evaluation in a 60 KVA single channel VSCF electrical generating system are included.

FOREWORD

This final report was submitted by the Armament and Electrical Systems Department of the General Electric Company under contract F33615-78-C-2029. The effort was sponsored by the Air Force Wright Aeronautical Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio under Project 3145, Task 314529, work unit 31452958, with Dr. W. U. Borger, AFWAL-POOS-2 as Project Engineer. John W. Butler, General Electric Company, was Program Manager and responsible for the overall effort.

This report covers work during the period from September 1978 to December 1981. The final report was submitted to AFWAL in January 1982.

The author gratefully acknowledges the contributions of Dr. C. Neugebauer, Dr. H. Webster, Dr. H.H. Glascock and J. Burgess of General Electric Corporate Research and Development Center; M. Sopchak, L. Ahern, P. Olski and R. Dyer of General Electric Solid State Applications Operation; and T.M. Wilson, W.P. Thomas, M.G. Wolters and D. Woodward of General Electric Armament & Electrical Systems Department.

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INTRODUCTION

1. OBJECTIVE

The objective of this program was to design, fabricate, and test, power hybrid semiconductor devices for use in 60 KVA Variable Speed Constant Frequency (VSCF), 400 Hz aircraft electrical power generation systems using rare earth/transition metal permanent magnets in the generator rotor. Extensive electrical and environmental (MIL-STD-883A) tests were to be accomplished on the power hybrids in addition to a demonstration of operation in a "breadboard" VSCF system.

This program is part of an overall Air Force effort to develop low life cycle cost, weight competitive, airborne electrical systems yielding high reliability, high quality MIL-E-23001B 400 Hz power. Power hybrid semiconductor devices offer the VSCF converter designer significant weight and volume savings, increased thermal capability, increased reliability, in addition to lower converter manufacturing costs when compared to utilization of discrete power semiconductor devices. Successful demonstration of these power hybrid semiconductor attributes will play a significant role in attaining the aforementioned Air Force goals.

The program was a structured 5-phase effort beginning with hybrid design and concluding with VSCF system tests and a reporting phase.

2. SCOPE

The following were completed as part of this effort.

a. design of a breadboard VSCF system using power hybrids,
b. design of power hybrid semiconductor devices for utilization in the power sections of the VSCF converter,
c. fabrication of power hybrids for rigorous electrical and environmental tests,
d. composition of a detailed performance test procedure for the breadboard VSCF system,
e. fabrication of a "semiproduction" quantity of power hybrids for use in the breadboard converter and for shipment to AFWAL for life testing, and
f. fabrication and test of the breadboard VSCF system using hybrids.

The program was accomplished in the following distinct phases:

Phase I - Design

Phase II - First Generation Hybrid Fabrication and System Design Completion

Phase III - First Generation Hybrid Tests

Phase IV - Second Generation Hybrid and VSCF System Fabrication

Phase V - VSCF System Tests

3. BACKGROUND

Present day aircraft require 3-phase, 400 Hz electric power. Beginning with the B-36, the requirement for this AC power aboard aircraft has drastically increased. Since aircraft engines run at widely varying speeds, some means must be provided to convert the variable speed to a constant frequency generator output. Various methods of providing a constant speed to a synchronous electrical machine from a variable speed shaft power source have been proposed and demonstrated. Most AC aircraft systems in use today employ a hydro-mechanical transmission to maintain constant input speed to a synchronous generator. The reliability of this type of 400 Hz power generation device can, at best, be described as fair.

With the introduction of the silicon controlled rectifier (SCR) in 1958, it became technically feasible to manufacture aircraft electrical systems in which a synchronous generator is mounted directly to the engine pad and the variable frequency power is converted to excellent quality 400 Hz power by solid state converters. This type of electronic power conversion has been termed Variable Speed Constant Frequency (VSCF). VSCF type power systems promise high reliability and maintainability and have demonstrated this capability in the industrial motor speed control industry where power conversion devices similar to those used in VSCF systems have become the standard. The application of VSCF type power equipment to aircraft electrical power generation was first initiated in 1972 on A-4 aircraft.

The results obtained in the A-4 program coupled with the ever-increasing high life cycle costs of hydromechanical devices was the underlying drive force in the selection of VSCF technology (30/40 KVA) for use on the U.S. Navy F-18 aircraft.

During the same above mentioned VSCF development period, the Air Force Materials Laboratory was leading the effort in the development of Rare Earth/Transition Metal permanent magnets. In 1972, permanent magnets with 20 MGOe magnetic energy product became commercially available. It was clear, at this point in time, that permanent magnet VSCF systems were technically feasible and highly desirable from a reliability, weight, volume, and cost standpoint. A contract, F33615-74-C-2037, was awarded by the Air Force Wright Aeronautical Laboratory to the General Electric Company to demonstrate a 150 KVA Samarium Cobalt VSCF starter/-generator system. The excellent promise of the above program has led the Air Force to further development of permanent magnet VSCF type systems. In August 1978, a contract, F33615-78-C-2200, was awarded by the Air Force Wright Aeronautical Laboratory to the General Electric Company to design and fabricate a Permanent Magnet Variable Speed Constant Frequency Power Generation System of the 60 KVA/channel level for flight test on the A-10 aircraft in the 1982 time period.

The converter portion of the VSCF systems has shown drastic size and weight reductions since the early days of VSCF going from a configuration of several packages to a configuration where the converter section is designed to "wrap" around the synchronous generator affording excellent cooling and reliability in nearly minimum system volume and weight. The majority of the converter weight and volume reductions have come from packaging expertise and miniaturization of electrical control functions. Further reductions in converter size and weight are possible through the application of miniaturization techniques to the semiconductor power sections of the converter. Additional benefits such as reliability increases, better junction-case thermal properties, less power loss and greater ease of converter assembly and maintenance are dependent on the continuing development of improved power switching modules containing SCR's. The thrust of this project was directed toward the development and test of power hybrid modules for utilization in the converter sections of 60 KVA Permanent Magnet Generator VSCF systems.

SECTION II

SUMMARY

1. CONCLUSIONS

The program objective, to design, fabricate and test SCR power modules for use in a 60KVA VSCF, 400 Hz aircraft electrical power generation systems using permanent magnets for the generator rotor has been successfully completed. Extensive electrical and environmental tests were performed on the power hybrids along with evaluation in a full operational 60 KVA VSCF electrical system.

The advantages of utilizing structured-copper and direct-bond copper, along with an aluminum enclosure, for SCR modules using large diameter silicon pellets, has become obvious.

With reference to the Power Hybrids, it has been demonstrated that hermetic dual SCR modules can be built which meet the requirements of a 60 KVA VSCF system; each SCR has current handling capability of 75 amperes rms with blocking voltage capability of 1200 volts peak. Furthermore, it has been demonstrated that the module provides considerably lower thermal resistance, less weight and -55°C minimum operating temperature.

All SCR's available today using 18mm diameter and larger pellets do not have their lower operating temperature range extended below -40°C without severe increases in thermal resistance due to the required dry interfaces. Table I illustrates the significant savings in weight and volume. In addition the large reduction in thermal resistance enables operation at significantly higher cold plate temperatures.

TABLE 1

COMPARISON OF CHARACTERISTICS

	POWER HYBRID MODULE	DISCRETE C159**
WEIGHT – LBS. EACH	0.25	0.34
WEIGHT SAVING/SYSTEM	4.0 ***	—
VOLUME – IN^3	2.77	5.47 **
THERMAL RESISTANCE °C/W – JUNCTION-TO-CASE	0.20	0.52 *
INTERNAL ELECTRICAL ISOLATION	YES	NO

* INCLUDES THERMAL RESISTANCE OF TYPICAL ELECTRICAL ISOLATION REQUIRED (0.22 °C/W (0.22 °C/W ADDED).

** COMPARABLE PACKAGE VOLUME FOR TWO DISCRETE SCR'S (SAME BASE PLATE AREA AS SCR MODULE).

*** INCLUDES ADDITIONAL WEIGHT SAVINGS FROM REDESIGN OF PULSE TRANSFORMER/DRIVER CIRCUIT PRINTED WIRE ASSEMBLY, ELIMINATION OF SOME MOUNTING HARDWARE AND STRUCTURE ON ULTIMATE INSTALLATION.

SECTION III

POWER HYBRID (SCR POWER MODULE)

1. DESIGN

The design of the SCR Power Module was accomplished in Phase I of the program. The performance requirements were established and documented in the Power Hybrid Specification (Appendix A) 283A8357. Figure 1 shows a photograph of the Power Hybrid.

The areas of consideration for subassembly design included pellet selection, pellet processing, high temperature polyimide polymer passivation, structured copper (a stress relief medium) and direct bonded copper-to-beryllia (electrical isolation). An illustration of the structured-copper used is shown in Figure 2.

The areas of consideration for the package design included a hermetic sealed aluminum enclosure for reliability, minimum weight and screw-type electrical termination to facilitate installation and removal. The built-in electrical isolation eliminates the necessity for a separate insulator such as "Kapton".

Appendix B gives a detailed description of the design features. Figure 3 shows the typical components for each SCR subassembly and Figure 4 shows the components of the complete module.

2. FABRICATION

A detailed description of the Phase II assembly methods for the modules appears in Appendix B. Approximately half of the modules were fabricated at the Corporate Research & Development Center in Schenectady, NY and the remainder were fabricated at the Solid State Applications Operations at Syracuse, NY.

3. MODULE TESTING

The 36 modules were tested in Phase III per the Test schedule as shown in Appendix C. The procedure and results of these tests were documented in the report "First Generation Hybrid Test Report" dated March 11, 1980, Appendix D.

Nine of the thirty-six modules tested passed all tests with the exception of one electrical test at low temperature which will be discussed later. Following completion of the 100% screening tests, through Sequence 7, 21 of the 36 modules exhibited no significant deterioration for test Sequences 8 through 15. Significant accomplishments of this program include:

1. Good temperature cycling performance
2. No open internal electrical connections, and

Figure 1. Power Hybrid Module 100280-20CN

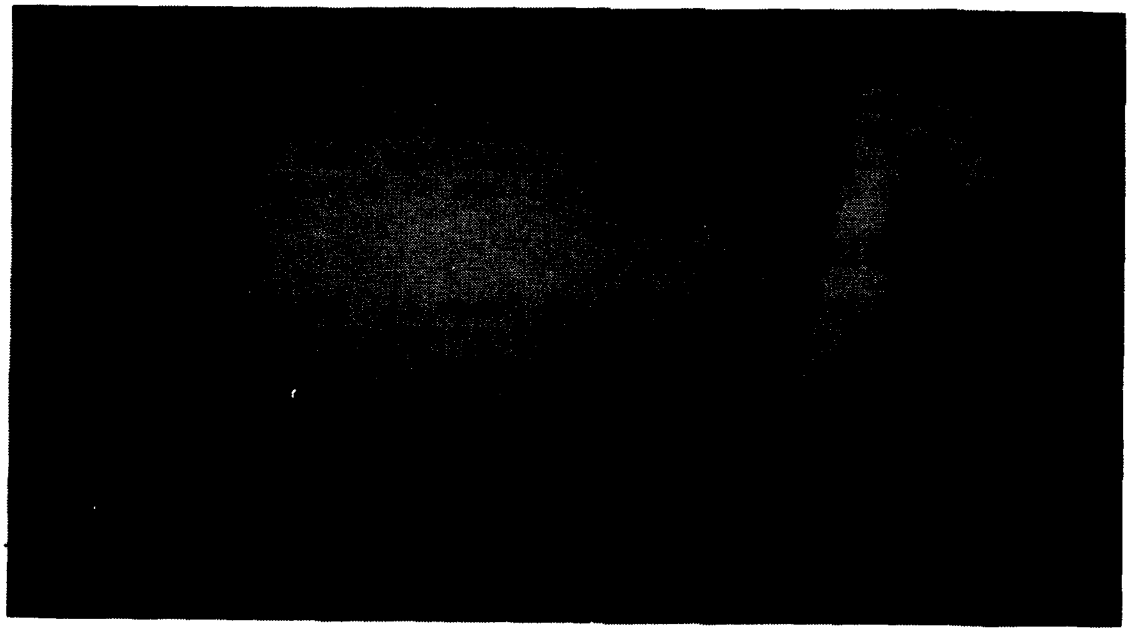

Figure 2. Structured Copper 29218

Figure 3. SCR Subassembly 100280-19CN

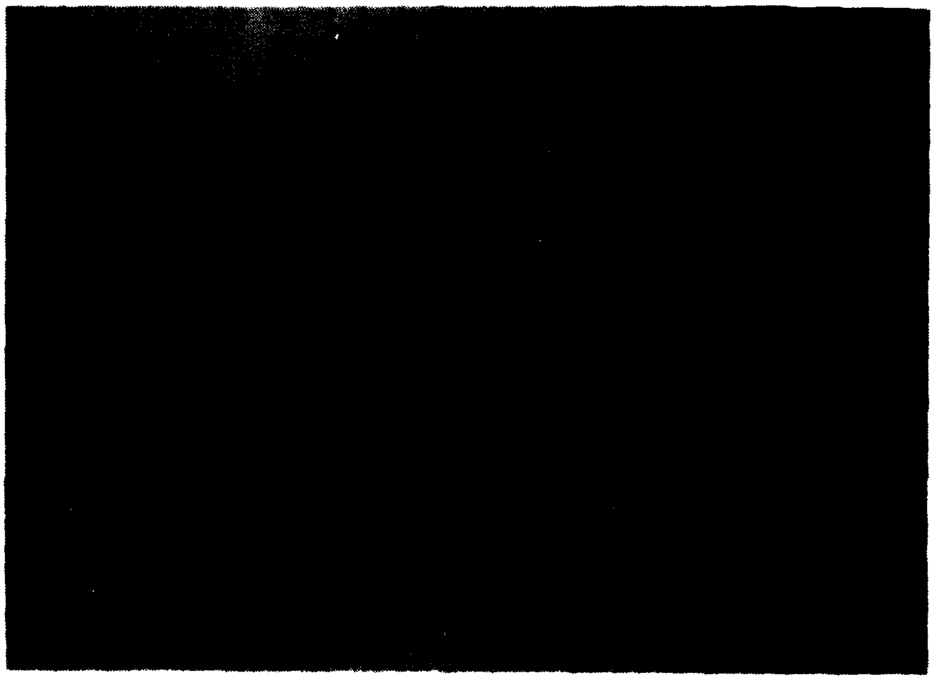

Figure 4. Power Hybrid Assembly 28581

3. No significant external damage for modules fabricated in accordance with the documented process.

4. FABRICATION OF 2ND GENERATION SCR MODULES

As a result of the failure analysis program conducted at the end of Phase III, several design and process changes (Table 2) were incorporated into the next 54 modules fabricated during Phase IV for use in the VSCF system test of Phase V. Figure 2 shows a sample of the module fabricated in Phase IV.

The fabrication of the 2nd generation hybrids was in a limited production environment at the Solid State Applications Operation in Syracuse, NY. Individual device serialization and history were maintained on all hybrids.

TABLE 2
MODIFICATION OF 1ST GENERATION HYBRIDS

- The internal copper straps were redesigned to reduce stress on the SCR subassemblies which had resulted in cracking of the silicon pellet. The straps were reduced in thickness from 0.020 inch to 0.010 inch and the large interconnecting strap which carries current from the top of one SCR to the bottom of the other SCR was modified to have a series of holes across its width. The internal copper straps also were all tin plated to improve solder bonding (Figure 6).

- The SCR gate leads were changed from rectangular cross section copper to round silver wires (Figure 3).

- The lower structured copper disc was assembled with its foil side toward the BeO disc.

- The module housing was redesigned to improve the lid solder seal (Figure 6).

- All fixtures and molds were redesigned to improve manufacturability, appearance and ability to meet physical dimension specifications (Figures 7 and 8).

- The modules were 100% tested for thermal resistance prior to lid seal. This enabled rework of modules with poor solder joints (Figure 9).

- The external copper straps, from the feed-thrus to the screw terminals, were reduced in thickness from 0.020 inch to 0.010 inch to provide ease of forming. This results in improved terminal positioning and reduces stress on the feed-thrus during forming (Figures 5 and 10).

One proposed change, namely to perform a blocking voltage life test on SCR subassemblies, was not done primarily because of lack of time to provide a means of heatsinking the subassemblies to prevent thermal runaway because of the high blocking power dissipation in the SCR.

a. Parts Procurement

All module parts required for Phase IV fabrication were procured during Phase IV except for the hermetic feed-through terminals and the SCR pellet assemblies. These were ordered during Phase II because of their long delivery times. At the start of Phase IV a quantity of 184 SCR's was on hand. This was felt to be sufficient to fabricate the required 54 modules.

b. Fabrication Details

Most of the design and process modifications described above definitely resulted in easier assembly and improved performance during Phase IV. A total of 59 modules were fabricated. Photos of the assembly fixtures used are shown in Figures 6 and 7.

The SCR subassemblies used in phase IV were obtained from the GE Discrete Semiconductor Device Center (DSDC) during Phase II. These were non-standard SCR's which employed special metallization and a polyimide passivation. Because the SCR's were known to be of marginal voltage capability and voltage stability, it was decided to return all 184 SCR's to DSDC for application of a second coating of the polyimide passivation. Tests on the SCR subassemblies before and after the recoating operation showed that the recoating operation definitely increased the quantity of the SCR's with 1200-volt capability. A total of 127 SCR's were delivered to the assemblies operation. However, it was soon learned that many of the SCR's downgraded in voltage capability during the soldering operations employed in the assembly of the modules. Additional SCR's, rejected during Phase II were recoated and retested. However, there were not enough available to make 54 modules with 1200-volt capability.

The solderability of the modules was greatly improved by the tin plating of all copper parts prior to assembly. Solder wetting was much better as evidenced by the distribution of thermal resistance measurements which were performed on each SCR in all modules prior to lid seal. It was found necessary to reflow the solder on approximately 30% of the modules to bring them within the specifications. During the reflow operation, solder was added to the interface between the subassembly and the module housing. Of the 59 modules fabricated, all 118 SCR's were less than the 0.2°C per watt limit except for seven SCR's which were between 0.20 and 0.26 and one which proved to be unrepairable.

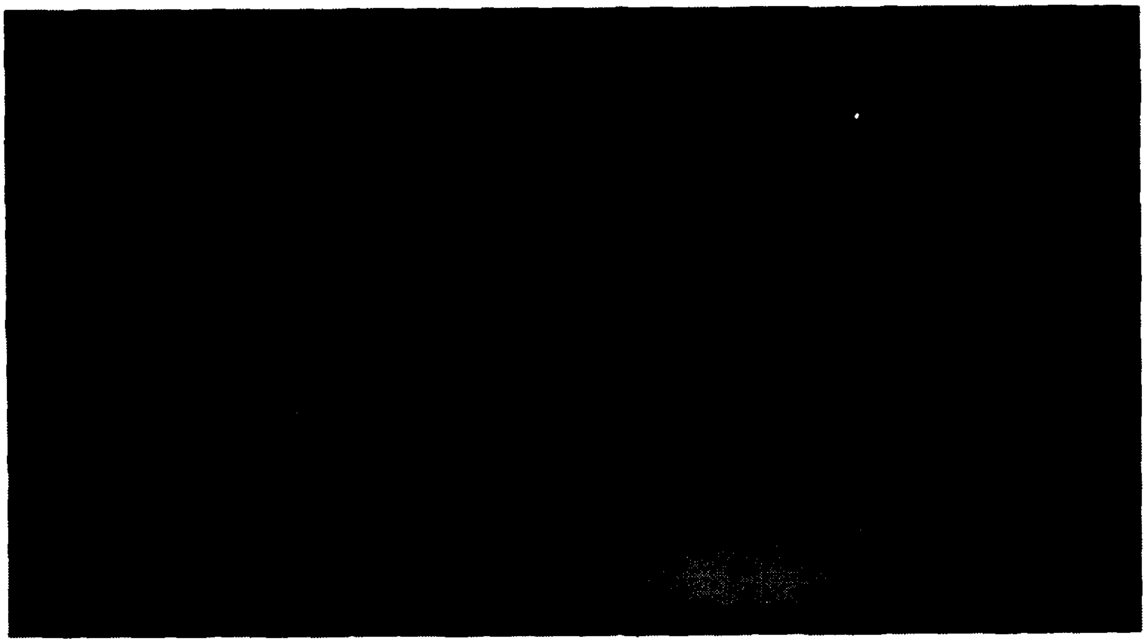

Figure 5. Internal Copper Straps 100280-18CN

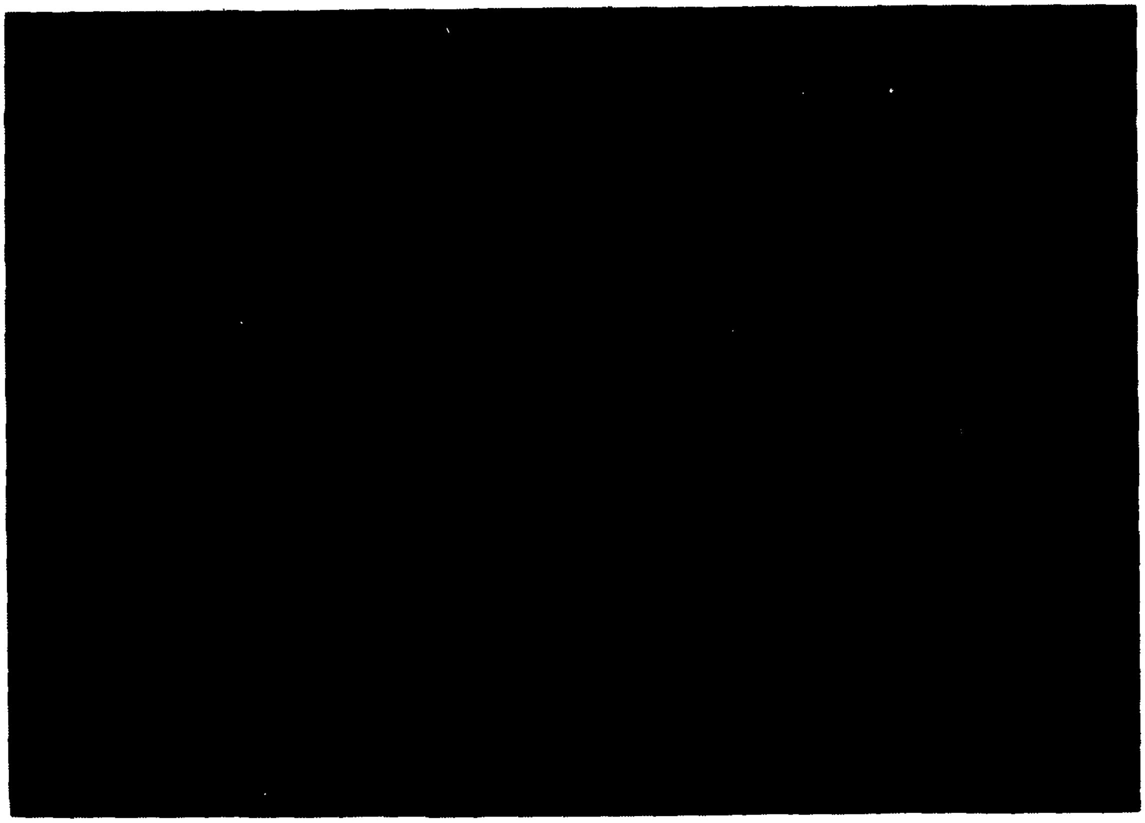

Figure 6. Module Housing and Terminations 100280-23CN

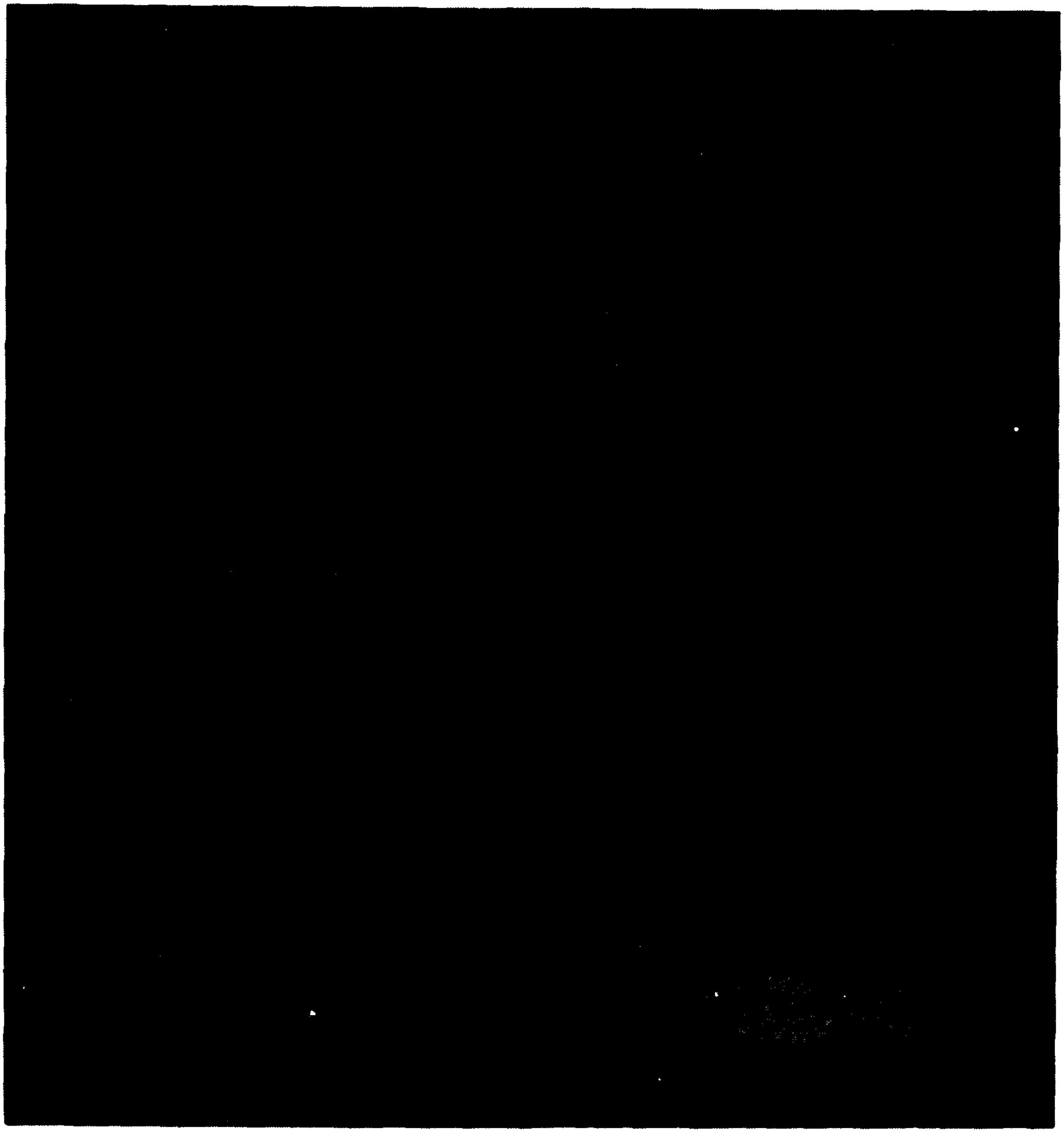

Figure 7. Subassembly Fixturing 100280-15CN

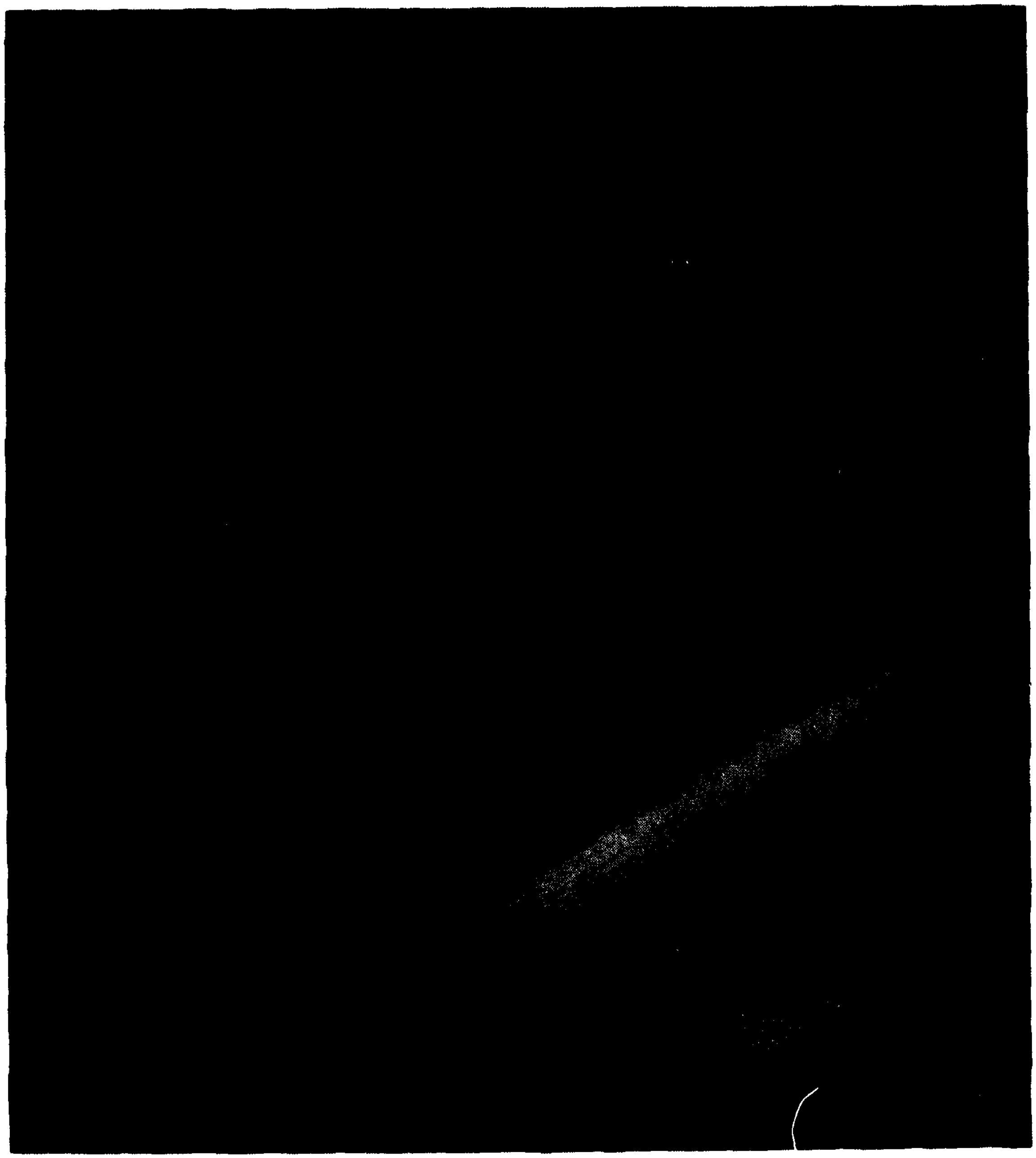

Figure 8. Module Fixturing 100280-17CN

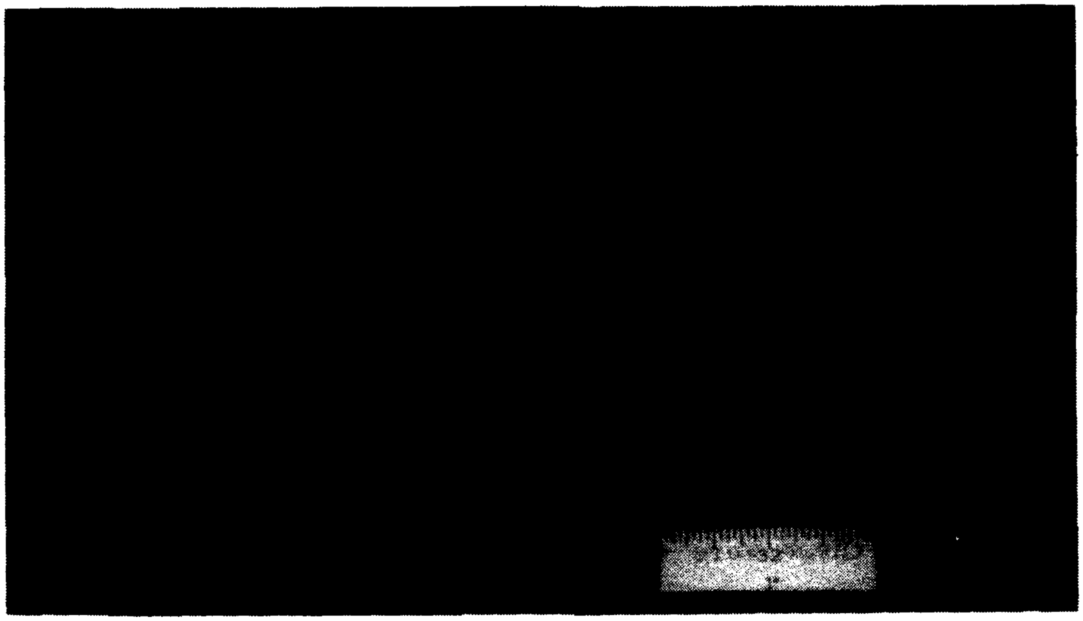

Figure 9. Module Assembly 100280-21CN

Figure 10. Complete Module Assembly 31973

One problem that exists with the module assembly is that the same solder is used in both the subassembly and for the attachment of the subassembly to the module housing. This results in some subassembly solder reflow during soldering of the subassemblies into the housing. Since it was found that additional solder improved the thermal resistance, perhaps a thicker solder preform would reduce or eliminate rework.

During assembly of the modules, a problem was encountered with peeling of the solder plating on the housing. Replating of the housings was necessary which was accomplished. Unfortunately, it was not possible to detect the defective plating until the SCR subassemblies were soldered into the housing. This resulted in the loss of a considerable number of SCR's as a result of rework.

Little trouble was encountered achieving hermaticity of the modules. Although all modules were checked for feed-thru hermaticity prior to insertion of the SCR subassemblies, a few modules were found to be leakers after assembly was completed. Again the use of the same solder throughout resulted in leaks due to reflow. Although several completed modules were found to leak, all but two of these were repaired.

Of the 59 modules fabricated, 56 were inputted to the testing program. One was rejected for high thermal resistance and two were unrepairable seal leakers.

5. TESTING OF PHASE IV HYBRIDS (2ND GENERATION)

Each of the hybrids (modules) were subjected to the tests as identified in sequence numbers 1 through 7 of Appendix C.

Twenty-one of the fifty-nine modules fabricated were classified as acceptable for further testing in a VSCF system and were delivered to Binghamton on November 7, 1980. The 21 included 3 modules which did not meet the -55° gate trigger specifications and 4 modules which blew fuses during the 108-hour blocking voltage burn-in test.

Thirty-three modules were delivered which were designated as electrical rejects. Most of these exhibited degradation of SCR blocking voltage capability during assembly or test to levels well below the 1200-volt specification limit.

The five remaining modules were assembly rejects. Two were case seal leakers, one was a thermal resistance reject and two failed the insulation resistance test indicating that the SCR's were not electrically isolated from the module housing.

Therefore, a total of 54 modules were shipped to AI&ESD, Binghamton on November 7, 1980, after completion of Test Sequences 1 through 7 specified in the contract.

SECTION IV

VSCF SYSTEM DESIGN

1. GENERAL

The 60 KVA VSCF PMG convertor package originally used on the A6 Starter-Generator Project was chosen to be the basic building block for the Breadboard. This included the (IPT'S) interphase transformers, controls, external differential fault current transformers and power supply. Capacitors from another 60 KVA VSCF system were used along with the printed wire assemblies derived from the 60 KVA Permanent Magnet Generator (PMG) Program. A new generator voltage regulator was designed and added to simulate a PMG generator.

The Breadboard schematics and assembly drawings were submitted under Data Item 9 dated 26 September 1979 (Reference 5).

When the 60 KVA PMG system changed from 6Ø to 9Ø it was more difficult to adapt the PWB's for use in this Breadboard. Design, documentation and fabrication of this unique VSCF Breadboard system was far more extensive a task than originally planned.

The convertor design includes the special circuits to provide permanent magnet generator simulations along with all the standard control and protective functions required of an electrical generating system. Figure 11 shows the control panel and Figure 12 shows the convertor package.

2. POWER HYBRID SECTION (FIGURE 13)

The power Hybrid section was separated from the main converter. All modules were mounted on an oil cooled heat exchanger. The individual SCR drive circuits were mounted on small printed circuit boards attached directly to each Hybrid Power Module.

3. CONVERTER

During the Breadboard checkout phase of the program, several problems were encountered which required modifications of the original circuits and Breadboard design:

a) An enlarged heat sink and a better thermal path from the power supply transistor to ultimate sink was required to overcome a high temperature problem.

b) A redesigned field regulator circuit was required to properly simulate the PMG requirement.

c) Additional cooling was required for the interphase transformers.

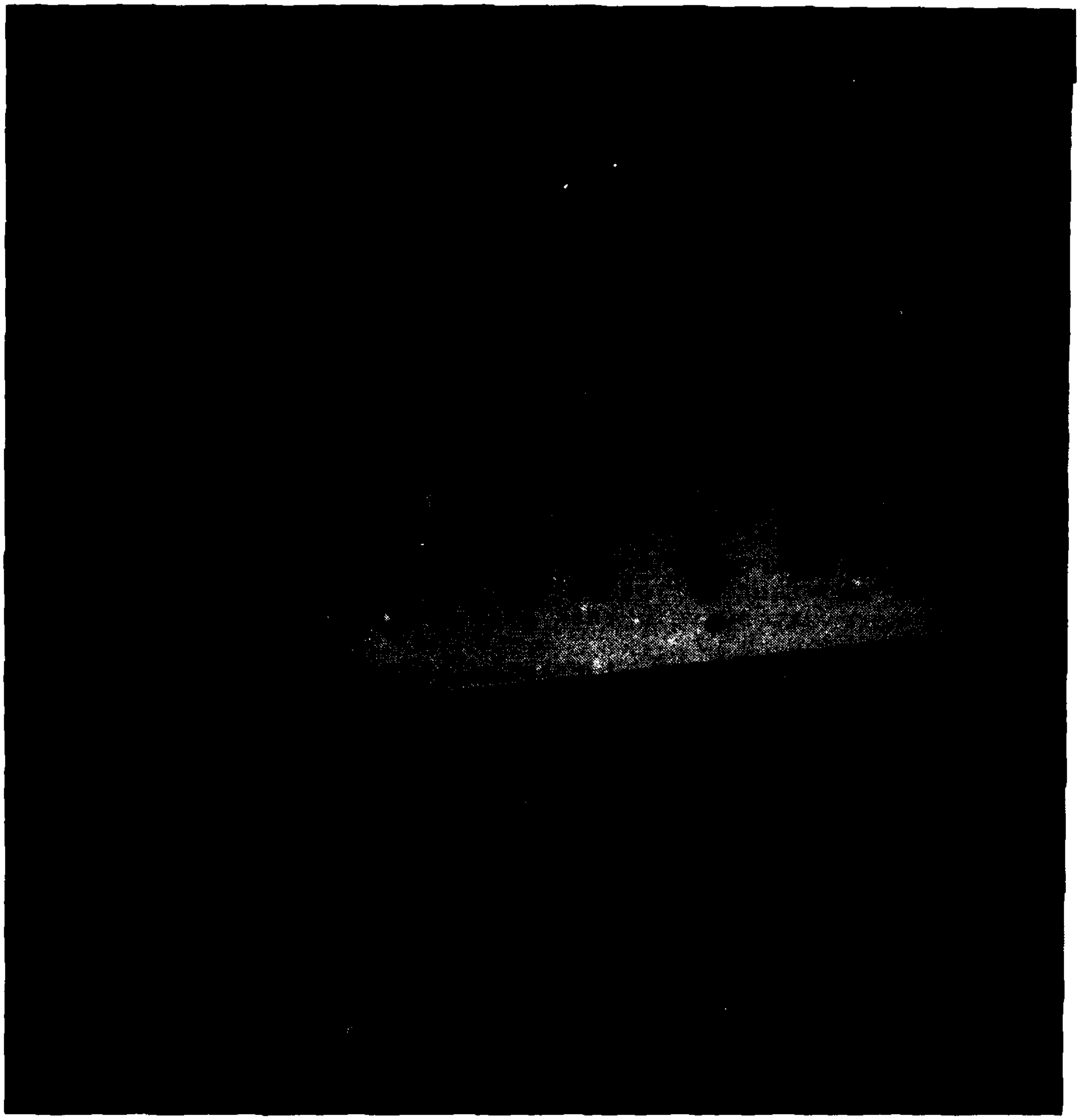

Figure 11. Control Panel 29984

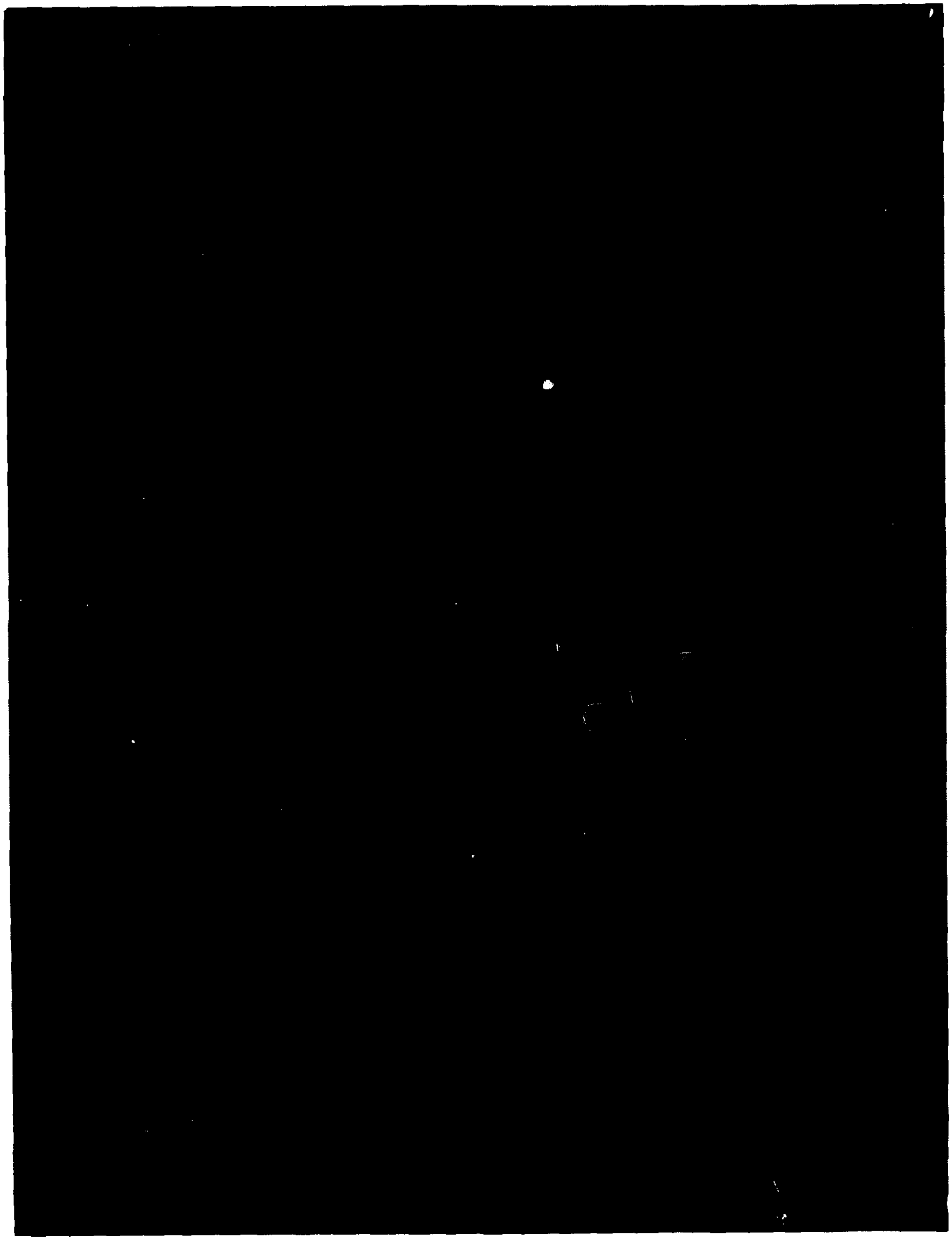

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Figure 12. Converter Package

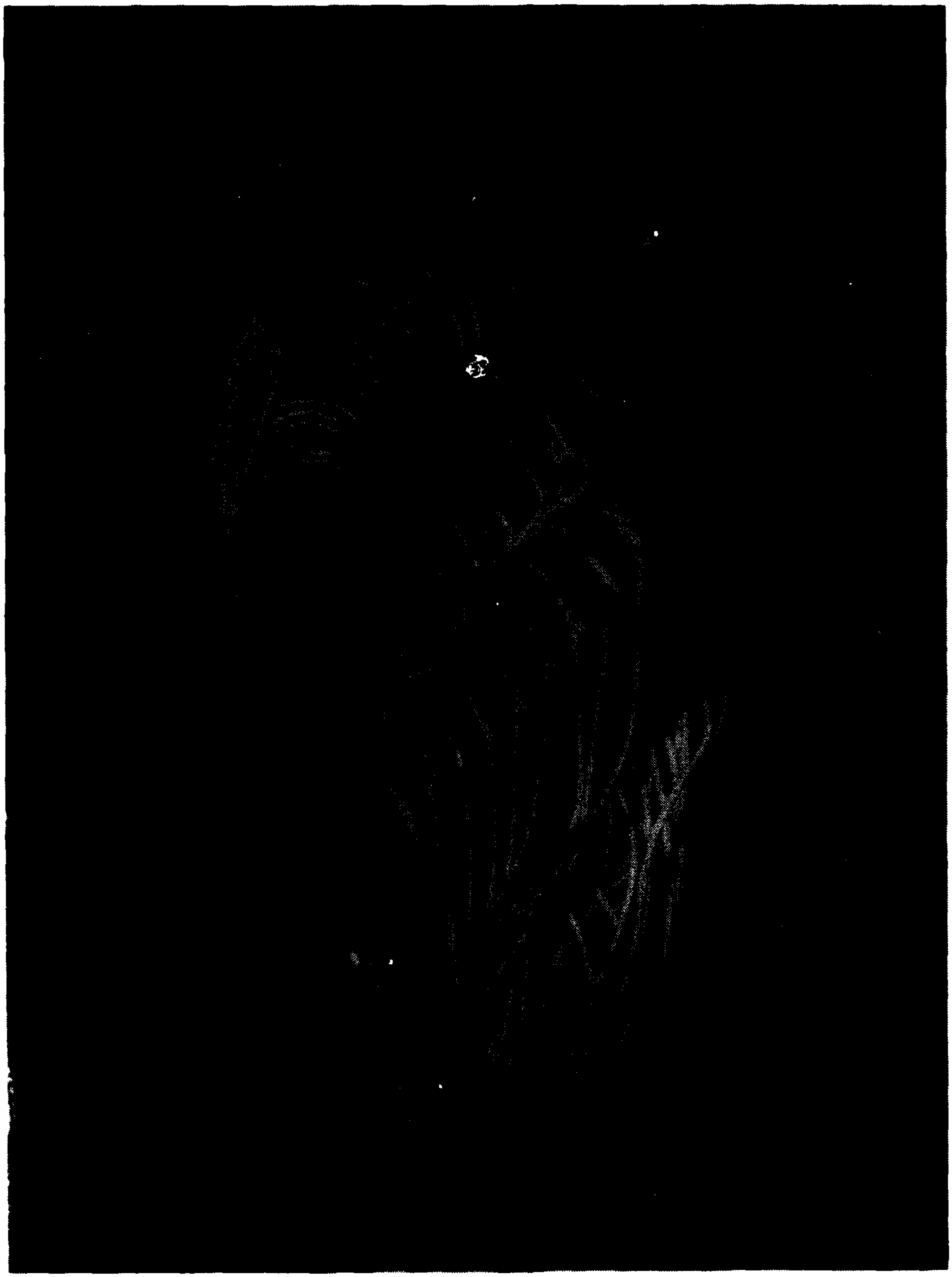

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Figure 13. Hybrid Power Section

4. GENERATOR

Since no suitable 60 KVA PMG 6-phase generator was available for this program, the wound rotor starter-generator from the A6 program was selected and plans made for its modification to simulate a PMG system.

The generator was plagued with several problems such as poor oil flow, shorted and open field rectifiers and excessive vibration requiring extra effort to investigate, identify and solve.

SECTION V

VSCF SYSTEM PERFORMANCE TEST

The Performance Test Procedure was submitted on 11 December 1979 under Data Item 10 and approved on 8 January 1980.

The VSCF System Performance Test Report was submitted in January 1982 for approval. A summary of the data taken along with the results were included and discussed (Appendix E).

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The program objective, to design, fabricate and test SCR power modules for use in a 60 KVA VSCF, 400 Hz aircraft electrical power generator systems using permanent magnets for the generator rotor has been successfully completed. Extensive electrical and environmental tests were performed on the power hybrids along with evaluation in a full operational 60 KVA VSCF electrical system.

The advantages of utilizing structured-copper and direct-bond copper, along with an aluminum enclosure, for SCR modules using large diameter silicon pellets, has become obvious.

With reference to the Power Hybrids, it has been demonstrated that hermetic dual SCR modules can be built which meet the requirements of a 60 KVA VSCF system; each SCR has current handling capability of 75 amperes rms with blocking voltage capability of 1200 volts peak. Furthermore, it has been demonstrated that the design of the module results in considerably lower thermal resistance, less weight and -55°C minimum operating temperature; all of which are better than the capabilities of available discrete SCR's of the same basic current handling capability.

The greatest problem encountered during the fabrication and testing of the modules was that the SCR blocking voltage capability simply degrades during both the assembly and testing operations. The SCR subassemblies for both Phase IV and Phase II were all obtained during Phase II since they were specially manufactured and long lead time was necessay. The techniques for applying the polyimide passivation coating were at that time not fully developed and had not yet been adapted for production use. Since that time, GE (SPD) Semiconductor Products Department has initiated use of polyimide on a production device, a 0.460 inch diameter SCR with solderable contacts used in their HI-LINE module. SPD has reported that the stability of these SCR's is now excellent. It is felt that the stability of the larger SCR's used for this program would also be exellent if SPD had the polyimide process developed and in production when the SCR's were procured for this program.

Most of the design improvements made at the start of Phase IV simplified the module assembly and resulted in less losses. However, the effects of one change are not so obvious. The internal copper strap thickness was reduced in thickness to reduce stress on the SCR's during mechanical and environmental tests as was evidenced by cracked silicon pellets found during the Phase III failure analyses. It was noted that during Sequence 7 of the Phase IV test program nine modules downgraded in voltage capa-

bility either due to the temperature cycling test or to the thermal shock resulting from immersion of the modules in 100°C glycol for the seal test. This performance was actually poorer than that recorded during Phase III for the same test sequence. Whether the copper strap thickness change was responsible or not for the poorer performance is unknown. It's possible that the unstable nature of the SCR blocking characteristics could be responsible.

It was found during rework of modules to improve thermal resistance that the addition of solder between the aluminum case and the lower structured copper disc produced a marked improvement. It is recommended that a thicker solder preform be specified on the drawings for future reference.

Indalloy 151 solder is used to bond together the various materials making up the internal subassembly. The same solder is then used to attach the two internal subassemblies to the module case. This results in reflow of some of the subassembly solder joints which is somewhat objectionable since the SCR again is exposed to high temperature which increases the possibility of voltage degradation. Furthermore, it makes rework of modules, when SCR's downgrade, very difficult. It would be much more desirable to use a lower melting point solder for attachment of the subassemblies to the module case.

Indalloy 151 solder was chosen to enhance thermal cycling and thermal fatigue (power cycling) performance. However, no thermal fatigue data exists on these modules.

While the technical performance of the Power Hybrid design has met the intended goals, and therefore made a significant contribution to electronic miniaturization, the estimated productions costs of the module, as designed, are not as low as desired.

2. RECOMMENDATIONS

Future projects should be directed toward changes in the methods and materials to reduce the expected end item production costs while retaining the fundamental ideas demonstrated in this project.

Thermal fatigue testing of the modules with the presently used solder interfaces in comparison to alternate solders (different melting points) would also be extremely useful.

APPENDIX A

POWER HYBRID SPECIFICATION

SIZE	283A8357	SHEET 1 OF 25	REV D

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED
A	1) SH 20, 21 & 23 REDRAWN WITH CHNG 2) SH 25 WAS SH 24 3) ADDED NEW SH 24 4) CHNG SHEET 22 ECN 283A8357-1	11/7/79	R. Wargo
B	1) CHNG METHOD OF DIMENSIONING AND ADDED DATUMS, ON SH 2 2) .705 WAS .71±.01 ON SH 3 3) CHNG NOTE 4.4, TABLE I & TABLE II 4) ADDED ITEM IDENT & VENDOR ECN 283A8357-2	1/4/80	R. Wargo
C	1) ADDED CAPTIVE HARDWARE SH 3 2) .0005 IN/IN WAS .005, SH 2 3) ADDED .51-.02 DIM, SH 2 ECN 283A8357-3	6/12/80	S.F. R. Wargo
D	1) 1.60 WAS 1.16 ON SH 25 ECN 283A8357-4	12/31/80	E.T. R. Wargo

CONTR NO F33615-78-C-2029

DOCUMENT REVISION	REVISION STATUS OF SHEETS																					
D	SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	REV	D	C	C	C	B	—	—	—	B	—	B	B	—	—	—	—	—	—	—	A	A

IDENTIFICATION OF THE "SUGGESTED SOURCE(S) OF SUPPLY" HEREON IS NOT TO BE CONSTRUED AS A GUARANTEE OF PRESENT OR CONTINUED AVAILABILITY AS A SOURCE OF SUPPLY FOR THE ITEM(S).

SH	22	23	24	25		
REV	A	A	A	D		

SPECIFICATION CONTROL DRAWING

SUBSTITUTIONS REQUIRE ENGINEERING APPROVAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:

FRACTIONS ± DECIMALS ± ANGLES ±

ALL SURFACES ✓

MATL—

SIGNATURES		DAY	MO	YR
DRAWN	R.A. Wargo	11	1	79
CHECKED	R.A. Wargo	8	5	79
ISSUED		10	5	79
		8	5	79
MATLS		8	5	79

SEMICONDUCTOR DEVICE, DUAL THYRISTOR

SIZE	CODE IDENT NO.	
A	89954	283A8357

SCALE NONE — SHEET 1 OF 25

FN 901 (2-77) PRINTED IN U.S.A.

DIST TO

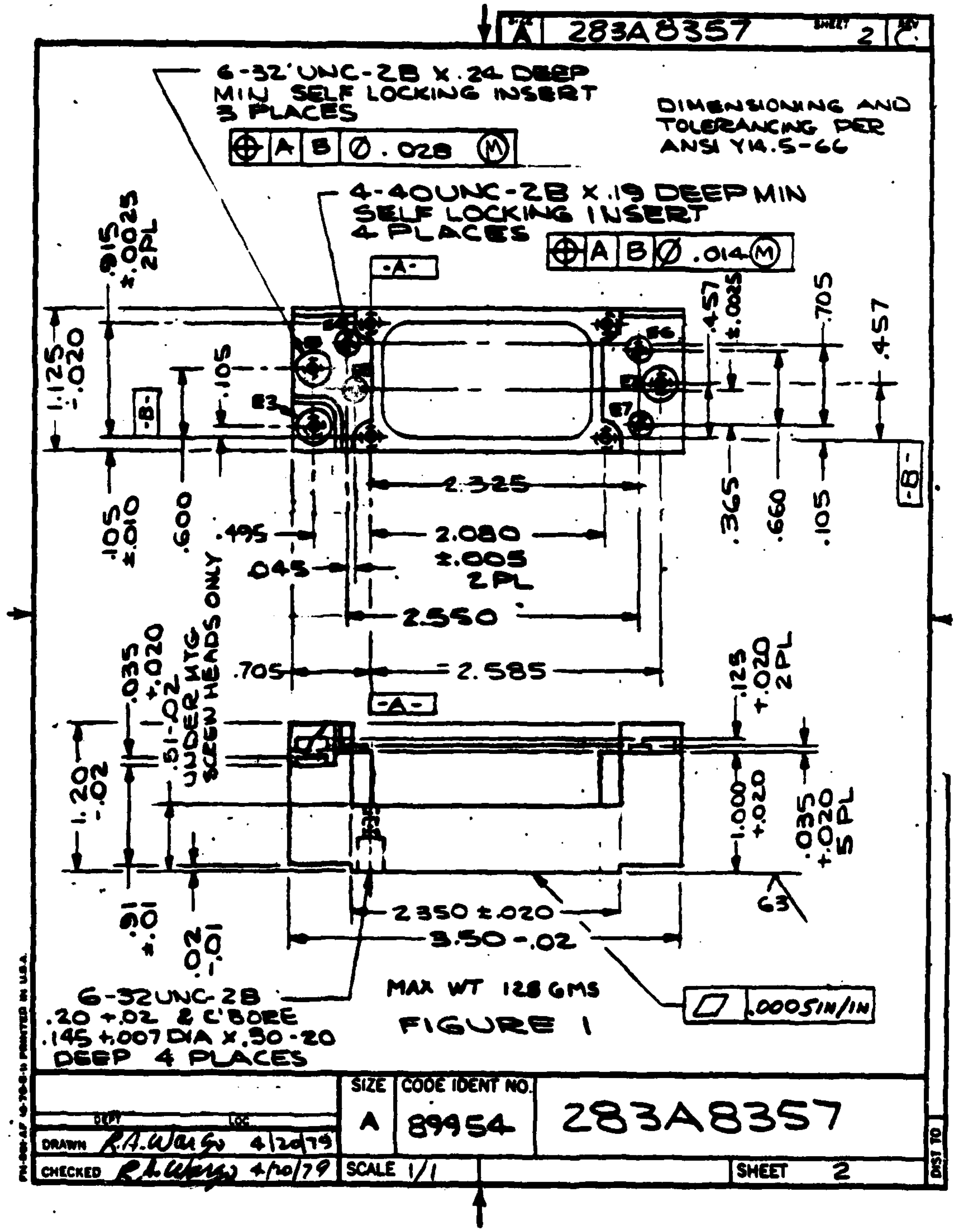
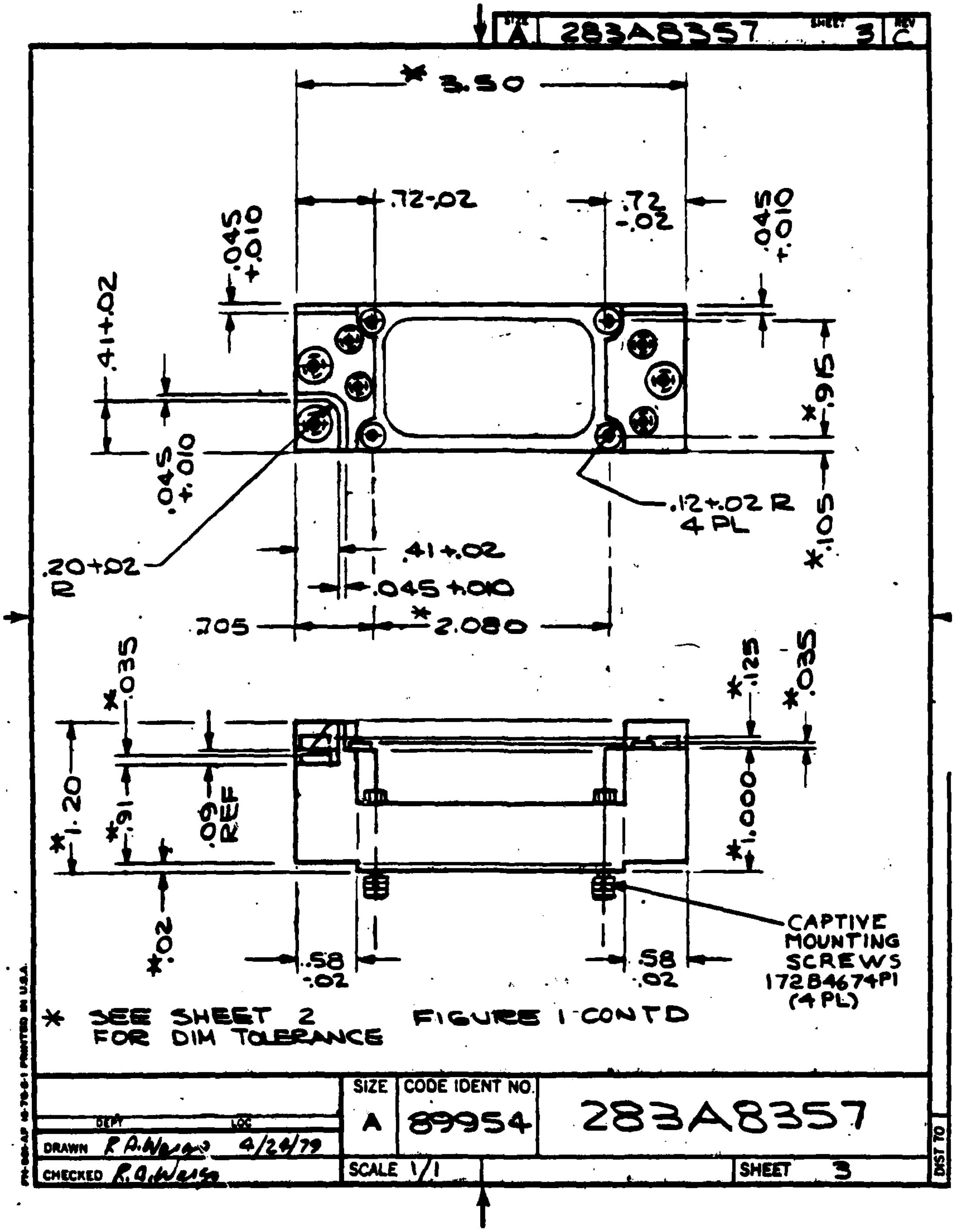

283A8357
6-32 UNC-2B X .24 DEEP
MIN SELF LOCKING INSERT
3 PLACES
A B Ø .028 M
DIMENSIONING AND
TOLERANCING PER
ANSI Y14.5-66
4-40UNC-2B X .19 DEEP MIN
SELF LOCKING INSERT
4 PLACES
A B Ø .014 M
-A-
-B-
2.325
2.080
±.005
2PL
2.550
2.585
UNDER MTG
SCREW HEADS ONLY
2.350 ±.020
3.50 -.02
6-32UNC-2B
.20 +.02 & C'BORE
.145 +.007 DIA X .30 -.20
DEEP 4 PLACES
MAX WT 128 GMS
.0005IN/IN
SIZE
A
CODE IDENT NO.
89954
283A8357
DRAWN
CHECKED
4/20/79
SCALE 1/1
SHEET 2

FIGURE 1


A 283A8357 3 C
* 3.50
.72-.02
.72 -.02
.045 +.010
.41+.02
.045 +.010
*.915
*.105
.12+.02 R 4 PL
.20+.02 R
.41+.02
.045+.010
.705
*2.080
*.035
*1.20
*.91
.09 REF
*.02
*.125
*.035
*1.000
.58 .02
.58 .02
CAPTIVE MOUNTING SCREWS 17284674P1 (4 PL)
* SEE SHEET 2 FOR DIM TOLERANCE
FIGURE 1 CONTD
SIZE A
CODE IDENT NO. 89954
283A8357
DRAWN R.A.Weiss 4/24/79
CHECKED R.A.Weiss
SCALE 1/1
SHEET 3

A 283A8357 SHEET 4 REV 2

SUGGESTED SOURCE(S)
OF SUPPLY:

GENERAL ELECTRIC COMPANY
SOLID STATE APPLICATIONS OPERATION
SYRACUSE, N.Y.
(FSCM NO NONE)

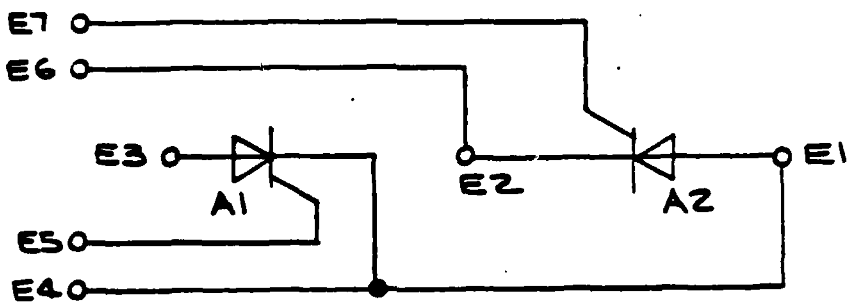


FIGURE 1A

ELEMENTARY DIAGRAM

PART NO	ITEM IDENTIFICATION NUMBER	EQPT REV
1	89954-143D586261	C

DRAWN R.A. Wargo 1/8/79	SIZE A	CODE IDENT NO. 89954
CHECKED R.A. Wargo 1/11/79	SCALE NONE	283A8357 SHEET 4

1.0 SCOPE

1.1 SCOPE. THIS DOCUMENT COVERS THE DETAILED REQUIREMENTS FOR A DUAL THYRISTOR MODULE TO BE USED IN A CRITICAL AIRCRAFT APPLICATION.

2.0 APPLICABLE DOCUMENTS

2.1 APPLICABLE DOCUMENTS. THE FOLLOWING GOVERNMENT DOCUMENTS OF THE REVISION AND OR AMENDMENT INDICATED, FORM A PART OF THIS SPECIFICATION TO THE EXTENT SPECIFIED HEREIN. ALL OTHER DOCUMENTS OF THE LATEST ISSUE OR AS OTHERWISE INDICATED, APPLY TO THE EXTENT SPECIFIED HEREIN.

SPECIFICATIONS MILITARY	
~~MIL-S-19500/204E~~	SEMICONDUCTOR DEVICES, THYRISTORS, SILICON
MIL-S-19500F	SEMICONDUCTOR DEVICES GENERAL SPECIFICATION FOR
MIL-M-38510D	MICROCIRCUIT GENERAL SPECIFICATION FOR
STANDARDS	
MIL-STD-750B	TEST METHODS FOR SEMICONDUCTOR DEVICES
MIL-STD-883B	TEST METHODS AND PROCEDURES FOR MICRO ELECTRONICS

3.0 REQUIREMENTS

3.1 DETAILED REQUIREMENTS. DESIGN, CONSTRUCTION AND PHYSICAL DIMENSIONS SHALL BE IN ACCORDANCE WITH FIGURE 1, FIGURE 1A AND ALL THE REQUIREMENTS SPECIFIED HEREIN.

3.1.1 PACKAGE. ALL DEVICES SUPPLIED UNDER THIS SPECIFICATION SHALL BE HERMETICALLY SEALED IN GLASS, METAL OR CERAMIC (OR COMBINATIONS OF THESE) PACKAGES. NO ORGANIC OR POLYMERIC MATERIALS (LACQUERS, VARNISHES, COATINGS, ADHESIVES, GREASES, ETC.) SHALL BE USED INSIDE THE MICROCIRCUIT PACKAGE EXCEPT SILICONES AND POLYIMIDES UNLESS OTHERWISE SPECIFIED. DESICANTS MAY BE USED IF EACH LOT IS SUBJECTED TO AND PASSES GROUP B, SUBGROUP 1b TESTS OF METHOD 5005 OF MIL-STD-883. POLYMER IMPREGNATIONS (BACKFILL, DOCKING, ETC.) OF THE MICROCIRCUIT PACKAGES SHALL NOT BE PERMITTED EXCEPT SILICONES AND POLYIMIDIES. PACKAGES USING GLASS FRIT SEAL SHALL HAVE GLASS ON THE MATING SURFACES ONLY AND THE INSIDE SURFACES OF THE CAVITY SHALL NOT BE COATED WITH THE SEAL GLASS. THE USE OF ROSIN BASE NON ACTIVATED ORGANIC SOLDERING FLUX IS PERMITTED

3.1.2 METALS. EXTERNAL METAL SURFACES SHALL BE CORROSION-RESISTANT OR SHALL BE PLATED OR TREATED TO RESIST CORROSION.

3.1.3 OTHER MATERIALS. EXTERNAL PARTS, ELEMENTS OR COATINGS INCLUDING MARKINGS SHALL BE INHERENTLY NON-NUTRIENT TO FUNGUS AND SHALL NOT BLISTER, CRACK, OUTGAS, SOFTEN, FLOW OR EXHIBIT DEFECTS THAT ADVERSELY AFFECT STORAGE, OPERATION, OR ENVIRONMENTAL CAPABILITIES OF MICRO-CIRCUITS DELIVERED TO THIS SPECIFICATION UNDER THE SPECIFIED TEST CONDITIONS.

3.1.4 DESIGN DOCUMENTATION. DESIGN, TOPOGRAPHY, AND SCHEMATIC CIRCUIT INFORMATION FOR ALL DEVICES SUPPLIED UNDER THIS SPECIFICATION SHALL BE SUBMITTED TO THE GENERAL ELECTRIC COMPANY, AEROSPACE INSTRUMENTS AND ELECTRICAL SYSTEMS DEPARTMENT.

THIS DESIGN DOCUMENTATION SHALL BE SUFFICIENT TO DEPICT COMPLETELY THE PHYSICAL AND ELECTRICAL CONSTRUCTION OF THE DEVICES SUPPLIED UNDER THIS SPECIFICATION, AND SHALL BE TRACEABLE TO THE SPECIFIC PART, DRAWING OR TYPE NUMBERS TO WHICH IT APPLIES, CONTROL SHALL BE ESTABLISHED FOR PARTS SPECIFICATIONS AND ANY REVISIONS SUCH THAT TRACABILITY EXISTS FROM FINISHED DEVICE TO METHODS AND PARTS USED IN MANUFACTURE OF SPECIFIED DEVICE.

3.1.4.1 DIE INTRACONNECTION PATTERN. THERE SHALL BE AN ENLARGED PHOTOGRAPH(S) OR DRAWINGS OR TRANSPARENCY, OR DIAZOTYPES OF THE MASK SET SHOWING THE SPECIFIC INTRACONNECTION PATTERN USED TO CONNECT THE ELEMENTS ON THE DIE SO THAT ELEMENTS USED AND THOSE NOT USED CAN BE EASILY DETERMINED. FOR FILM HYBRID OR MULTICHIP MICROCIRCUITS, THIS REQUIREMENT SHALL APPLY TO THE SUBSTRATE AND ALL CONDUCTOR PATTERNS AND ACTIVE OR PASSIVE CIRCUIT ELEMENTS DEPOSITED THEREON, AS WELL AS TO SEMI-CONDUCTOR DIE, AS APPLICABLE.

3.1.4.2 DIE TO TERMINAL INTERCONNECTION. THERE SHALL BE AN ENLARGED PHOTOGRAPH(S), TRANSPARENCY, OR DRAWING(S) TO SCALE AND OF SUFFICIENT MAGNIFICATION TO CLEARLY DEPICT THE INTERCONNECTION PATTERN FOR ALL CONNECTIONS MADE BY WIRE OR RIBBON BONDING, BEAM LEADS OR OTHER METHODS BETWEEN THE SEMICONDUCTOR DIE, OTHER ELEMENTS OF THE MICRO-CIRCUIT, SUBSTRATE(S) AND PACKAGE TERMINALS OR LANDS AS APPLICABLE TO THE SPECIFIC TYPE OF MICROCIRCUIT SUPPLIED. IF THESE INTERCONNECTIONS SHOW CLEARLY ON THE DIE INTRACONNECTION PATTERN PHOTOGRAPH, AN ADDITIONAL PHOTOGRAPH OR DRAWING IS NOT REQUIRED.

3.1.5 INTERNAL CONDUCTORS. INTERNAL THIN FILM CONDUCTORS ON SILICON DIE OR SUBSTRATE (METALIZATION STRIPES, CONTACT AREAS, BONDING INTERFACES, ETC.) SHALL BE DESIGNED SO THAT NO PROPERLY FABRICATED CONDUCTOR SHALL EXPERIENCE IN NORMAL OPERATION (AT WORST CASE SPECIFIED OPERATING CONDITIONS), A CURRENT DENSITY IN EXCESS OF THE MAXIMUM ALLOWABLE VALUE SHOWN BELOW FOR THE APPLICABLE CONDUCTOR MATERIAL:

CONDUCTOR MATERIAL	MAXIMUM ALLOWABLE CURRENT DENSITY
ALUMINUM(99.99% PURE OR DOPED)WITHOUT GLASSIVATION	2×10^5 A/cm^2
ALUMINUM(99.99% PURE OR DOPED) GLASSIVATED (SEE 3.5.5.4)	5×10^5 A/cm^2
GOLD	6×10^5 A/cm^2
ALL OTHER(UNLESS OTHERWISE SPECIFIED)	2×10^5 A/cm^2

DRAWN R.A. Wargo 1/9/79	SIZE A	CODE IDENT NO. 89954	283A8357
CHECKED R.A. Wargo 1/10/79	SCALE NONE		SHEET 6

3.1.5 (continued)

THE CURRENT DENSITY SHALL BE CALCULATED AT THE POINT(S) OF MAXIMUM CURRENT DENSITY (i.e. GREATEST CURRENT (SEE 3.1.5A) PER UNIT CROSS SECTION) FOR THE SPECIFIC DEVICE TYPE AND SCHEMATIC OR CONFIGURATION.

A. USE A CURRENT VALUE EQUAL TO THE MAXIMUM CONTINUOUS CURRENT (AT FULL FANOUT FOR DIGITALS OR AT MAXIMUM LOAD FOR LINEARS) OR EQUAL TO THE SIMPLE TIME-AVERAGED CURRENT OBTAINED AT MAXIMUM RATED FREQUENCY AND DUTY CYCLE WITH MAXIMUM LOAD, WHICHEVER RESULTS IN THE GREATER CURRENT VALUE AT THE POINT(S) OF MAXIMUM CURRENT DENSITY. THIS CURRENT VALUE SHALL BE DETERMINED AT THE MAXIMUM RECOMMENDED SUPPLY VOLTAGE(S) AND WITH THE CURRENT ASSUMED TO BE UNIFORM OVER THE ENTIRE CONDUCTOR CROSS SECTIONAL AREA.

B. USE THE MINIMUM ALLOWED METAL THICKNESS PER MANUFACTURING SPECIFICATIONS AND CONTROLS.

C. USE THE MINIMUM ACTUAL DESIGN CONDUCTOR WIDTHS (NOT MASK WIDTHS) INCLUDING APPROPRIATE ALLOWANCE FOR NARROWING OR UNDERCUTTING EXPERIENCED IN METAL ETCHING.

D. AREAS OF BARRIER METALS AND NON-CONDUCTING MATERIAL SHALL NOT BE INCLUDED IN THE CALCULATION OF CONDUCTOR CROSS SECTION.

THICK FILM CONDUCTORS ON HYBRID MICROCIRCUITS OR MULTICHIP SUBSTRATES (METALLIZATION STRIPS, BONDING INTERFACES, ETC.) SHALL BE DESIGNED SO THAT NO PROPERLY FABRICATED CONDUCTOR SHALL DISSIPATE MORE THAN 4 WATTS/CM^2 WHEN CARRYING MAXIMUM DESIGN CURRENT.

3.1.5.1 INTERNAL LEAD WIRES. INTERNAL LEAD WIRES OR OTHER CONDUCTORS WHICH ARE NOT IN THERMAL CONTACT WITH A SUBSTRATE ALONG THEIR ENTIRE LENGTH (SUCH AS WIRE OR RIBBON CONDUCTORS) SHALL BE DESIGNED TO EXPERIENCE, AT MAXIMUM RATED CURRENT, A CONTINUOUS CURRENT FOR DIRECT CURRENT, OR AN RMS CURRENT (PEAK CURRENT DIVIDED BY $\sqrt{2}$), FOR ALTERNATING OR PULSED CURRENT, NOT TO EXCEED THE VALUES ESTABLISHED BY THE FOLLOWING RELATIONSHIP.

$$I = Kd^{3/2}$$

WHERE: I = MAXIMUM ALLOWED CURRENT IN AMPERES.
d = DIAMETER IN INCHES FOR ROUND WIRE (OR EQUIVALENT ROUND WIRE DIAMETER WHICH WOULD PROVIDE THE SAME CROSS-SECTIONAL AREA FOR OTHER THAN ROUND WIRE INTERNAL CONDUCTOR).
K = A CONSTANT TAKEN FROM THE TABLE A FOR THE APPLICABLE WIRE OR CONDUCTOR LENGTH AND COMPOSITION USED IN THE DEVICE.

	SIZE	CODE IDENT NO.	
DEPT LOC	A	89954	283A8357
DRAWN R.A.Wargo 1/9/79			
CHECKED R.A.Wargo 1/10/79	SCALE NONE		SHEET 7

3.1.5.1 (continued) TABLE A

COMPOSITION	"K" VALUES FOR BOND-TO-BOND TOTAL CONDUCTOR LENGTH	
	LENGTH ≤ 0.040" (0.10 cm)	LENGTH ≥ 0.040" (0.10cm)
ALUMINUM	22,000	15,200
GOLD	30,000	20,500
COPPER	30,000	20,500
SILVER	15,000	10,500
ALL OTHERS	9,000	6,300

3.1.5.2 VERIFICATION OF GLASSIVATION LAYER INTEGRITY. WHERE THE CURRENT DENSITY OF ALUMINUM METALLIZATION FOR A DEVICE TYPE TO BE QUALIFIED EXCEEDS THE ALLOWABLE CURRENT DENSITY FOR UNGLASSIVATED ALUMINUM, THE DEVICE TYPE MUST BE SUBJECTED TO AND PASS THE REQUIREMENTS OF MIL-STD-883 TEST METHOD 2021 PRIOR TO QUALIFICATION AND A PHOTOGRAPH OF THE ETCHED DIE SHALL BE SUBMITTED WITH THE QUALIFICATION TEST REPORT. ONE RESUBMISSION IS PERMITTED AT TWICE THE SAMPLE SIZE. CHANGES IN DESIGN, MATERIALS, OR PROCESS WHICH AFFECT CURRENT DENSITY SHALL ALSO BE EVALUATED USING MIL-STD-883 TEST METHOD 2021.

3.2 ELECTRICAL CHARACTERISTICS. ELECTRICAL CHARACTERISTICS AND RATINGS SHALL BE IN ACCORDANCE WITH TABLES II, III AND IV. SEE MIL-S-19500 FOR DEFINITIONS OF SYMBOLS AND TERMS.

3.2.1 APPLICATION. TYPICAL APPLICATION IS GIVEN IN TABLE IV.

3.2.2 DIELECTRIC STRENGTH. THE DIELECTRIC SHALL EXCEED 2000 VOLTS (RMS) AT SEA LEVEL. ALL BARE CONDUCTIVE SURFACES SHALL BE SEPARATED BY 0.40 INCHES MINIMUM AND THE MINIMUM CREEPAGE DISTANCE SHALL BE 0.65 INCHES: EXCEPT THAT THE DISTANCES BETWEEN A GATE CONDUCTOR TO ITS ASSOCIATED CATHODE SHALL BE 0.05 INCHES MINIMUM THRU AIR AND 0.07 INCHES CREEPAGE DISTANCE. DIELECTRIC STRENGTH SHALL EXCEED 1200 VOLTS (RMS) AT 70,000 FT ALTITUDE.

3.3 QUALIFICATION INSPECTION. MODULE SHALL MEET THE REQUIREMENTS OF GROUP A INSPECTION AS DEFINED IN PARAGRAPH 4.4, GROUP A,B&C INSPECTION AS DEFINED IN TABLE V OF THIS SPECIFICATION.

3.4 SCREENING. EACH MODULE SHALL BE SUBJECTED TO AND SHALL PASS THE REQUIREMENTS SPECIFIED IN TABLE I.

3.5 QUALITY CONFORMANCE TESTING - TESTS SHALL BE PERFORMED PER PARAGRAPH 4.3

3.6 MARKING - EACH MODULE SHALL BE LEGIBLY AND PERMANENTLY MARKED PER MIL-M-38510 WITH THE MANUFACTURER'S NAME OR SYMBOL, DATE CODE, DEVICE SERIAL NUMBER AND PART IDENTIFICATION NUMBER. DATE CODES SHALL INDICATE SUBLOT. A SUBLOT SHALL REPRESENT NOT MORE THAN SIX WEEKS PRODUCTION. DO NOT MARK WITH THIS DRAWING NUMBER.

	SIZE	CODE IDENT NO.	
DEPT LOC	A	89954	283A8357
DRAWN R.A.Weigs 1/9/79			
CHECKED R.A.Weigs 1/11/79	SCALE NONE		SHEET 8

DIST TO

3.7 SUBSTITUTION OF MATERIALS AND PROCESSES

THE MANUFACTURER SHALL NOTIFY THE BUYER IN WRITING OF ANY CHANGES, AFFECTING ELECTRICAL CHARACTERISTICS, MECHANICAL CONFIGURATION, MATERIALS, OR ABILITY TO MEET PERFORMANCE, ENVIRONMENTAL OR LIFE REQUIREMENTS. PRIOR APPROVAL OF SUCH CHANGES BY BUYER SHALL BE REQUIRED.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 RESPONSIBILITY FOR INSPECTION. UNLESS OTHERWISE SPECIFIED IN THE PURCHASE ORDER, THE SUPPLIER IS RESPONSIBLE FOR THE PERFORMANCE OF ALL INSPECTION REQUIREMENTS AS SPECIFIED HEREIN. EXCEPT AS OTHERWISE SPECIFIED IN THE PURCHASE ORDER, THE SUPPLIER MAY USE HIS OWN OR ANY OTHER FACILITIES SUITABLE FOR THE PERFORMANCE OF THE INSPECTION REQUIREMENTS SPECIFIED HEREIN, UNLESS DISAPPROVED BY GENERAL ELECTRIC. GENERAL ELECTRIC RESERVES THE RIGHT TO PERFORM ANY OF THE INSPECTIONS SET FORTH IN THE SPECIFICATION WHERE SUCH INSPECTIONS ARE DEEMED NECESSARY TO ASSURE SUPPLIES AND SERVICES CONFORM TO PRESCRIBED REQUIREMENTS.

4.2 QUALIFICATION INSPECTION CONSISTS OF GROUPS A,B AND C INSPECTION.

4.3 QUALITY CONFORMANCE INSPECTION SHALL CONSIST OF GROUP A INSPECTION.

4.4 GROUP A INSPECTION SHALL CONSIST OF THE EXAMINATIONS AND TESTS LISTED BELOW. THIS INSPECTION SHALL BE PERFORMED ON DEVICES WHICH HAVE COMPLETED THE SCREENING OF PARAGRAPH 3.4 TEST CONDITIONS AND LIMITS SHALL BE IN ACCORDANCE WITH TABLE III.

SUBGROUPS MAY BE SEGREGATED AT THE CONVENIENCE OF THE MANUFACTURER HOWEVER, EACH INSPECTION SUBLOT SHALL BE INCLUDED IN EACH SUBGROUP. THE LTPD SHALL BE 10% FOR EACH SUBGROUP. SEE MIL-S-19500 FOR EXPLANATION OF TERMS AND SYMBOLS.

25°C TESTS: V_{TM}, V_{TON}, I_H, V_{RSM}, V_{DSM}, I_{GT1}, V_{GT1}

125°C TESTS: TURN OFF TIME, STATIC DV/DT, V_{GT2}, I_{DRM}, I_{RRM}

-55°C TESTS: I_H, V_{RSM}, V_{DSM}, V_{GT3}, I_{GT3}

4.5 INTERNAL VISUAL INSPECTION - INTERNAL VISUAL INSPECTION OF THE MODULE SHALL BE PERFORMED BY THE MANUFACTURER PRIOR TO ENCLOSURE AND/OR ENCAPSULATION. THE INSPECTION SHALL BE PERFORMED PER THE REQUIREMENTS OF MIL-STD-883, METHOD 2014, DETAILED ITEMS OF, INSPECTION SHALL BE SPECIFIED IN THE MANUFACTURER'S DRAWINGS AND PROCESS INSTRUCTIONS.

DEPT / LOC	SIZE	CODE IDENT NO.	283A8357
DRAWN R.A. Walgo 1/9/79	A	89954	
CHECKED R.O. Wargo 1/11/79	SCALE NONE		SHEET 9

DIST TO

5. PREPARATION FOR DELIVERY

5.1 PREPARATION. UNLESS OTHERWISE SPECIFIED, THE ITEMS SHALL CONFORM TO MIL-M-38510.

6.0 NOTES (NOT APPLICABLE).

TABLE I

SCREENING TESTS

EXAMINATION OR TEST	MIL-STD-883	
	METHOD	DETAILS
HIGH TEMPERATURE STORAGE	1008	48 HRS MIN TEST CONDITION B
TEMPERATURE CYCLING	1010.2	TEST COND C, EXCEPT T_{MIN} = - 55°C AND 30 MIN DWELL AT EACH TEMPERATURE EXTREME. 10 CYCLES
BLOCKING BURN-IN	1040 MIL-STD-750	TEST COND A T_C = 125°C 96 HRS RKG = 00 APPLIED VOLTAGE V_{DRM} & V_{RRM} SINE WAVE
SEAL	1014.1	STANDARD LEAK RATE 5×10^{-6} atm. cc/sec

	SIZE	CODE IDENT NO.	
DEPT LOC	A	89954	283A8357
DRAWN R.A.Wargo 11/9/79			
CHECKED R.A.Wargo 11/11/79	SCALE NONE		SHEET 11

TABLE II - MAXIMUM RATINGS AT T_J = -55 TO 125°C, UNLESS OTHERWISE SPECIFIED

PART NUMBER	1		
PARAMETER			UNITS
STORAGE TEMPERATURE RANGE, T_{stg}		-55 TO + 150	°C
JUNCTION OPERATING TEMPERATURE RANGE, T_J		-55 TO + 125	°C
REPETITIVE PEAK OFF-STATE VOLTAGE, V_{DRM}	1200		VOLTS
REPETITIVE PEAK REVERSE VOLTAGE, V_{RRM}	1200		VOLTS
NON-REPETITIVE PEAK REVERSE VOLTAGE, V_{RSM}	1400		VOLTS
RMS ON-STATE CURRENT, $I_{T(RMS)}$ CONTINUOUS	75		AMPS (RMS)
PEAK NON-REPETITIVE SURGE CURRENT, I_{TSM} (SEE FIGURE 3A)	1600		AMPS
PEAK SURGE WITH CONTROL CURRENT, I_{TSM1} (SEE FIGURE 3B)	1600		AMPS
PEAK SINUSOIDAL SURGE CURRENT, I_{TSM2} (SEE FIGURE 3B)	3000		AMPS
NON REPETITIVE PEAK OFF STATE VOLTAGE, V_{DSM}			
TC = +25°C TO 125°C	1400		VOLTS
TC = -55°C TO 25°C	1200		VOLTS
CRITICAL RATE OF RISE OF ON-STATE CURRENT, d_i/d_t, DURING TURN-ON, 2400 Hz REPETITIVE (SEE FIGURE 4)	30		AMPS/USEC
PEAK GATE POWER DISSIPATION, P_{GM}	200		WATTS
AT PULSE WIDTH = 10 μSEC, T_C = +25°C			
AVERAGE GATE POWER DISSIPATION, $P_{G(AV)}$	2		WATTS

DEPT LOC	SIZE	CODE IDENT NO.	283A8357
DRAWN R.A. Wargo 1/4/79	A	89954	
CHECKED R.A. Wargo 1/11/79	SCALE NONE		SHEET 12

DIST TO

FN-90I-AF (11-78) PRINTED IN USA

SIZE A	283A8357	SHEET 13	REV –

TABLE III - PRIMARY ELECTRICAL CHARACTERISTICS AT T_J = -55 TO + 125°C, UNLESS OTHERWISE SPECIFIED

PART NUMBER	1	
PARAMETER		UNITS
PEAK ON-STATE VOLTAGE V_{TM}, T_C = 25°C DUTY CYCLE .01% I_{TM} = 200 AMP (PEAK)	2.7	VOLTS
HOLDING CURRENT, I_H INITIAL FWD. CURRENT=2AMPS ANODE SUPPLY = 24 VDC T_C = +25° C	500	mAdc
TURN-ON VOLTAGE, V_{TO} SEE FIGURE 5A & 5B, T_C = 25°C	8	VOLTS
TURN-OFF TIME t_{q1} CONVENTIONAL CIRCUIT TURNOFF, T_C = 125°C (SEE FIGURE 6)	50	USEC
REPETITIVE PEAK REVERSE AND OFF-STATE CURRENT, V_{DRM}, V_{RRM}, I_{RRM}, I_{DRM}	15	mAdc
GATE CURRENT TO TRIGGER, V_d = 6Vdc, R_L = 3 OHMS		
I_{gt1} MAXIMUM, 25°C	150	mAdc
I_{gt3} MAXIMUM, -55°C	250	mAdc
GATE VOLTAGE TO TRIGGER V_{gt1} MAXIMUM, V_D = 6Vdc, R_L = 3 OHMS, T_C = 25°C,	3.0	Vdc
V_{gt2} MINIMUM, V_{DRM}, R_L = 1000 OHMS, T_C = 125°C	0.25	Vdc
V_{gt3} MAXIMUM, V_D= 6Vdc, R_L = 3 OHMS, T_C= -55°C	5.0	V_{dc}
THERMAL RESISTANCE, JUNCTION TO BASE $R_{\theta JB}$, MAX SEE FIGURE 7, EACH JUNCTION	0.20	°C/W
CRITICAL EXPONENTIAL RATE OF OFF-STATE VOLTAGE RISE, T_C = 125°C, V_D = 700 V(pk)	400	V/μSEC
HERMETIC SEAL, STD. LEAK RATE PER MIL-STD-883A.	$5X10^{-6}$	atm - cc/sec

DEPT	LOC	SIZE	CODE IDENT NO.	
DRAWN R. H. Walsh 1/9/79		A	89954	283A8357
CHECKED R. H. Walsh 1/11/79		SCALE		SHEET 13

DIST TO

FN 906 AF (11-76) PRINTED IN USA

TABLE IV - PRIMARY ELECTRICAL APPLICATION AT T_J = -55 TO +125°C, UNLESS OTHERWISE SPECIFIED

PART NUMBER		
PARAMETER		UNITS
AVERAGE CURRENT AT T_B = 100°C, I_T(AV) (FIGURE 2)		
CONTINUOUS	14	AMPS, DC
5 MINUTES	21	AMPS, DC
10 SECONDS	40	AMPS, DC
RMS CURRENT AT T_B = +100°C, $I_{T(RMS)}$, (FIG 2)		
CONTINUOUS	39	AMPS, RMS
5 MINUTES	58	AMPS, RMS
10 SECONDS	117	AMPS, RMS
PEAK CURRENT AT T_B = +100°C, I_{TM}, (FIG 2)		
CONTINUOUS	133.8	AMPS, PEAK
5 MINUTES	195.0	AMPS, PEAK
10 SECONDS	369.0	AMPS, PEAK
RATE OF RISE OF ON-STATE CURRENT, di/dt	10	A/usec
PEAK SWITCHING VOLTAGE	900	VOLTS, PEAK
TURN-OFF TIME	50	µSEC

TYPICAL VSCF SCR CURRENT WAVEFORM (IDEALIZED) [ACTUAL PULSES/HALF CYCLE = (fgen/400) X ½)] ; 1200 HZ ≤ fgen ≤ 2400 HZ ; $T_{GEN} = \frac{1}{fgen}$

$$P.W. = \left(\frac{Tgen}{3}\right) + \left(\frac{ITM}{di/dt}\right)$$

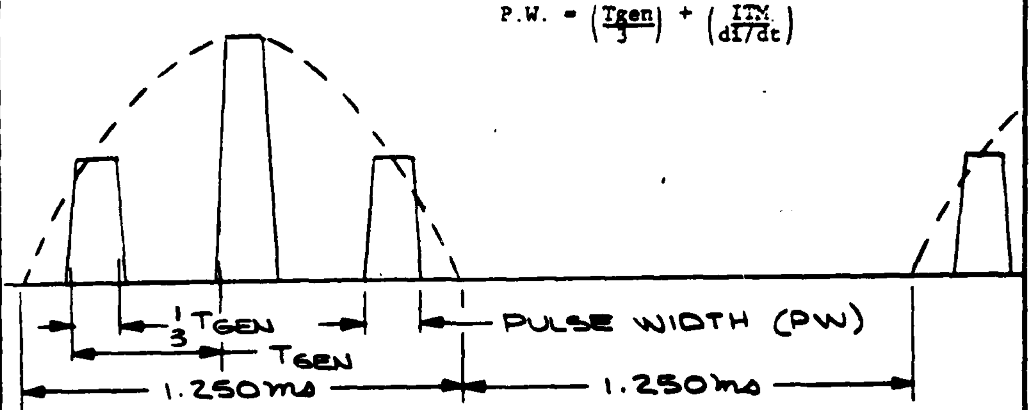


FIGURE 2 (SEE TABLE V)

	SIZE	CODE IDENT NO.	
DEPT / LOC	A	89954	283A8357
DRAWN K.A. Wong 1/8/79			
CHECKED R.A. Wong 1/8/79	SCALE		SHEET 14

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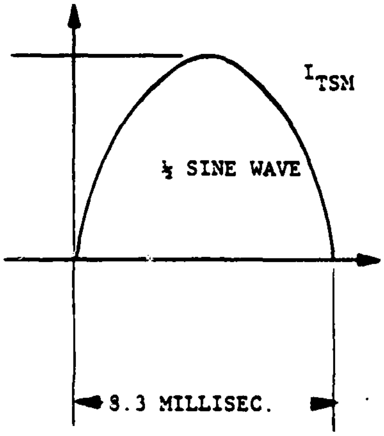
DIST TO:



CONDITIONS:

2.1 - T_C = + 125° ± 3°C

2.2 - WORKING V_{RRM} = MAXIMUM RATED

2.3 - NON-REP. REVERSE VOLTAGE = V_{RSM} MAXIMUM RATED.

2.4 - PEAK SURGE = I_{TSM} IN TABLE I

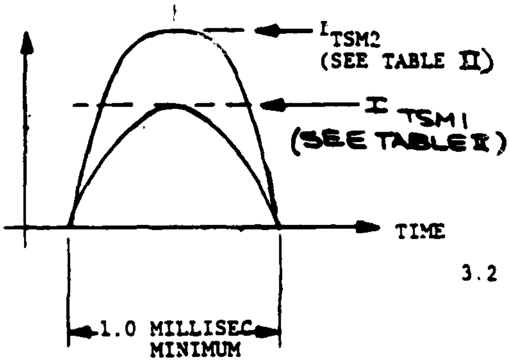
2.5 - TIME BETWEEN SURGES = 15 SECONDS MAXIMUM

2.6 - GATE TRIGGER = 15V+ 10%; 25 OHMS ±10%

2.7 - AFTER THIS TEST, WHEN $T_J \leq$ 125°C THE DEVICE MUST MEET V_{DRM}, V_{RRM}, V_{DSM}, V_{RSM} REQUIREMENTS.

DEFINITION OF I_{TSM}

FIGURE 3A



SURGE REQUIREMENTS
FIGURE 3B

NOTES:

3.1 I_{TSM1}: IMMEDIATELY FOLLOWING I_{TSM1}, FOR AN INTERVAL OF 20 MILLSEC MAX. SCR PERFORMANCE TO BE DEFINED BY THIS DRAWING, EXCEPT THAT:

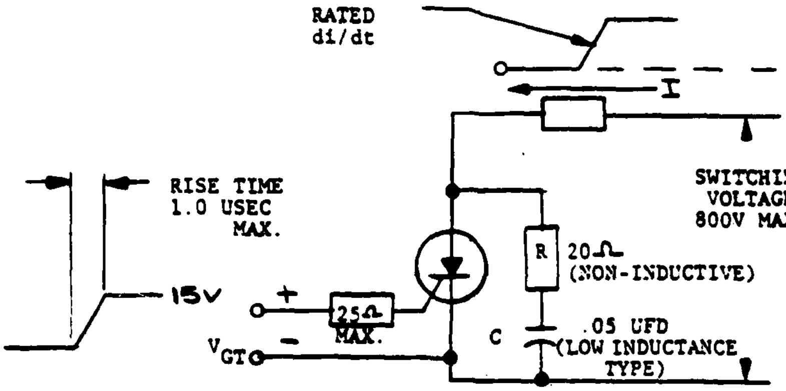
A. TURNOFF TIME (tq1) =200USEC MAX
B. TURNOFF REAPPLIED dv/dt=100V/USEC MIN.
C. EXPONENTIAL dv/dt = 100V/µSEC MIN, GATE OPEN
D. AFTER 20 MILLISEC INTERVAL, DEVICE MUST MEET ALL PERFORMANCE REQUIREMENTS OF THIS DRAWING.

3.2 I_{TSM2}: IMMEDIATELY AFTER I_{TSM2}, CONTROL IS NOT REQUIRED; HOWEVER, THE DEVICE MUST MEET ALL PERFORMANCE REQUIREMENTS OF THIS DRAWING IMMEDIATELY AFTER T_J RETURNS TO 125°C

3.3 JUNCTION TEMPERATURE AT THE BEGINNING OF THE PULSE SHALL BE + 125°C

DEPT / LOC	SIZE A	CODE IDENT NO. 89954	283A8357
DRAWN R.A. Wargo 11/79			
CHECKED R.A. Wargo 11/79	SCALE NONE		SHEET 15

FN 80I-AF (11-76) PRINTED IN USA



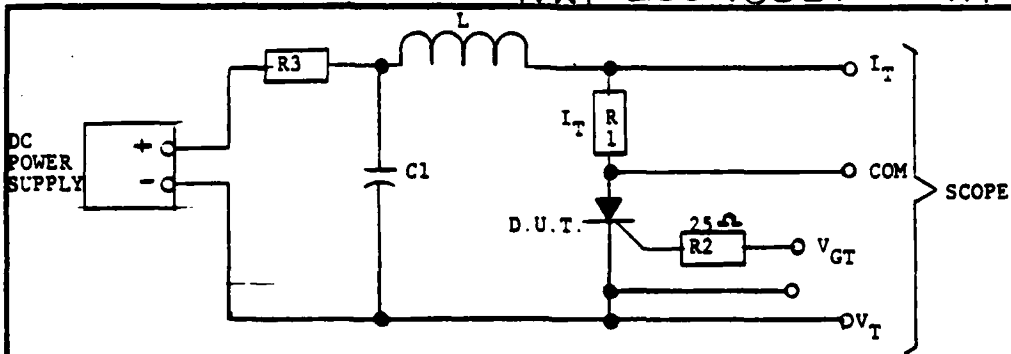
NOTE:

4.1 THE RATED di/dt FOR THIS SCR IS IN ADDITION TO THE DISCHARGE OF THE RC SNUBBER CIRCUIT SHOWN IN PARALLEL WITH THE SCR. (FOR ALL HIGH FREQUENCY RATINGS THE SCR AND SNUBBER IS THE DEVICE TESTED).

FIGURE 4

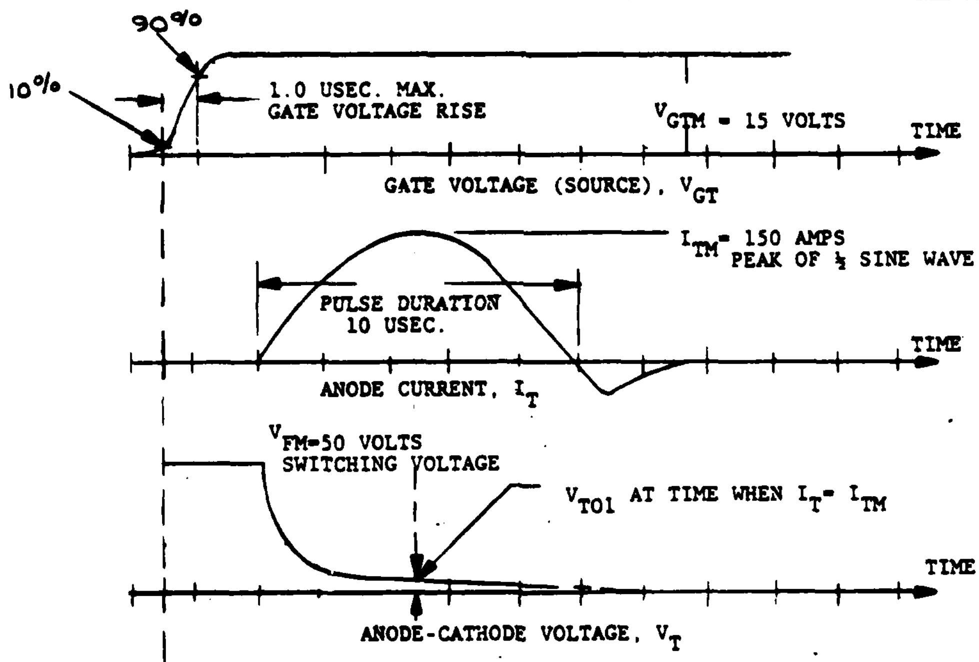
	SIZE	CODE IDENT NO.	
DEPT LOC	A	89954	283A8357
DRAWN R A Wargo 1/9/79			
CHECKED R. A Wargo 1/11/79	SCALE NONE		SHEET 16

FN-301-AF (4-76) PRINTED IN USA



TURN-ON VOLTAGE TEST CIRCUIT

FIGURE 5A

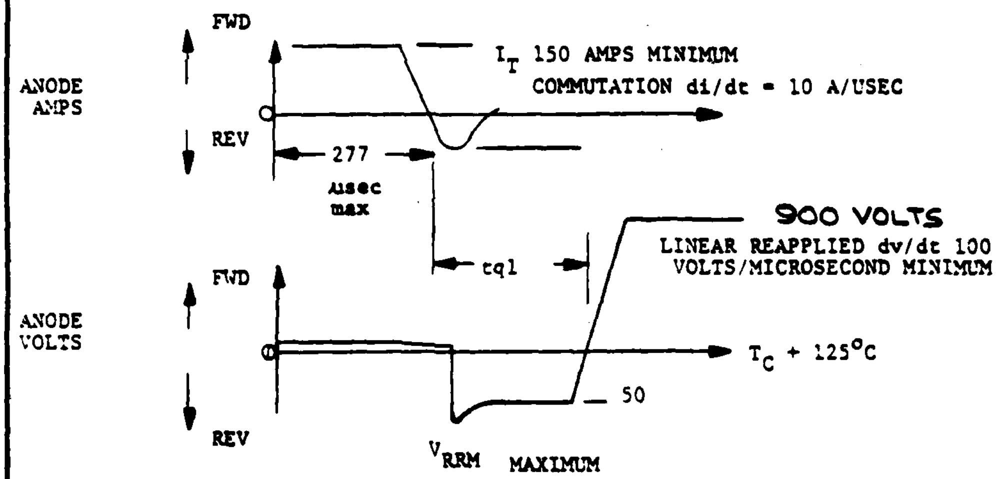


TURN-ON VOLTAGE WAVEFORMS

FIGURE 5B

DEPT / LOC	SIZE	CODE IDENT NO.	283A8357	
DRAWN R.A. Waigo 1/9/79	A	89954		
CHECKED R.A. Waigo 1/11/79	SCALE NONE		SHEET 17	DIST TO

FN-901-AF (11-76) PRINTED IN USA



REP. RATE:

TEST MAY BE 1.0 HZ. IN ADDITION DEVICE MUST BE CAPABLE OF PASSING AT 2400 HZ, AND WITH AN OPERATING CASE TEMPERATURE OF 100°C AND I_{TM} = 369 A PEAK WITH CURRENT WAVEFORM AS SHOWN IN FIGURE 2 FOR A PERIOD OF 10 SECONDS DURATION.

CONVENTIONAL CIRCUIT

COMMUTATED TURN-OFF TIME. (WITH REVERSE VOLTAGE)

FIGURE 6

DEPT LOC	SIZE	CODE IDENT NO.	283A8357
DRAWN R.A.Wargo 1/9/79	A	89954	
CHECKED R.P.Wargo 1/11/79	SCALE NONE		SHEET 18

FN-901-AF (11-76) PRINTED IN USA

DIST TO

SIZE A	283A8357	SHEET 19	REV —

TABLE I
GROUP B INSPECTION

EXAMINATION OR TEST	# MIL-STD-883 / ∂ MIL-STD-750 METHOD	DETAILS	LTDP	SYMBOL	LIMITS MIN	LIMITS MAX	UNITS
SUBGROUP 1			20				
EXTERNAL VISUAL	#2009.1	BASE SHALL BE FLAT WITH NO PROJECTIONS OR FOREIGN MATERIAL					
INSULATION RESISTANCE	#1003	TEST CONDITION F, MOUNTED ON AN ALUMINUM PLATE, MAX. LEAKAGE = 1µA					

DEPT	LOC	SIZE	CODE IDENT NO.	
DRAWN R.A. Waigu 5/7/79		A	89954	283A8357
CHECKED R.A. Waigu 5/8/79		SCALE		SHEET 19

DIST TO

PN-500-AF 10-70-8-11 PRINTED IN U.S.A.

TABLE V
GROUP B INSPECTION

EXAMINATION OR TEST	#MIL-STD-883 @ MIL-STD-750 METHOD	DETAILS	LTDP	SYMBOL	LIMITS MIN	MAX	UNIT
SUBGROUP 2			10		—	—	—
THERMAL SHOCK (TEMPERATURE CYCLING)	#1010.1	COND C, EXCEPT T_{MIN}= -55 C AND 30 MIN DWELL @ EACH EXTREME TEMPERATURE					
THERMAL SHOCK (GLASS STRAIN)	#1011.1	TEST COND A			—	—	—
MOISTURE RESISTANCE	#1004.2	OMIT INITIAL CONDITIONING & APPLIED VOLTAGE			—	—	—
SUBGROUP 3			10				
BLOCKING LIFE	@1040	$V_{RM}=V_{DRM}$ $T_C=122^{o}C$ t=500 HOURS			—	—	—

DEPT / LOC	SIZE A	CODE IDENT NO. 89954	283A8357
DRAWN R.A. WARGO 1/9/79			
CHECKED R.A. WARGO 1/9/79	SCALE NONE		SHEET 20

TABLE V
GROUP B INSPECTION

EXAMINATION OR TEST	# MIL-STD-883 @ MIL-STD-750 METHOD	DETAILS	LTDP	SYMBOL	LIMITS MIN	MAX	UNIT
SUBGROUP 4							
THERMAL CHARACTERISTICS	@ 4081	T_2=100°C MAX T_1= 80°C MIN (SEE FIG. 7) I_{F1}=75A MAX; I_{F2}=2A	20	$R_{\theta JB}$	-	.20	°C/W
END POINTS (SUBGROUP 2,3,4)							
REVERSE BLOCKING CURRENT	@ 4211	AC METHOD, BIAS COND D V_{RM}=1200V(pk)		I_{RRM}	-	20	mAdc
FORWARD BLOCKING CURRENT	@ 4206	AC METHOD, BIAS COND. D V_{DM} =1200V(pk)		I_{DRM}	-	20	mAdc
GATE TRIGGER VOLTAGE AND GATE TRIGGER CURRENT	@ 4221	V_1=5.0 Vdc R_E=25 OHMS R_L=3.0 OHMS MAX V_2=6.0 Vdc		V_{GT} I_{GT}	- -	3.0 150	Vdc mAdc
HERMETIC SEAL	# 1014	TEST COND. A1 & C					

DEPT LCC	SIZE A	CODE IDENT NO. 89954	283A8357
DRAWN R.A WARGO 5/8/77			
CHECKED R.A WARGO 5/8/77	SCALE NONE		SHEET 21

DIST TO

TABLE V (CONT'D)
GROUP C INSPECTION

EXAMINATION OR TEST	# MIL-STD-883 @ MIL-STD-750 METHOD	DETAILS	LTPD	SYMBOL	LIMITS MIN	LIMITS MAX	UNIT
SUBGROUP 1			20	-	-	-	-
PHYSICAL DIMENSIONS	#2016	SEE FIGURES 2 & 3		-	-	-	-
SHOCK	#2002.1	TEST COND A EXCEPT NON-OPERATING 30g 11±2msec	-	-	-	-	-
VIBRATION FATIGUE	#2005	NON-OPERATING PEAK ACCELERATION 5g	-	-	-	-	-
VIBRATION, VARIABLE FREQUENCY	#2007.1	100 TO 1,000 Hz, 10G	-	-	-	-	-
ENDPOINTS (SAME AS GROUP B, SUB-GROUP 1,2,3 &4)				-	-	-	-
SUBGROUP 2 BAROMETRIC PRESSURE REDUCED	#1001	30mm Hg, (70KFT) $V_{RM}=V_{DRM}$ = RATED, 60 SEC	10	-	-	500	uA
SALT ATMOSPHERE	#1009.1	COND A	-	-	-	-	-
END POINT (SEAL)	#1014	TEST COND A1&C	10	-	-	-	-
BLOCKING LIFE	@1040	$V_{RM}=V_{DRM}$ $T_C=122°C$ t =1000 HRS		-	-	-	-
ENDPOINTS (SUBGROUP 3) REVERSE BLOCKING CURRENT	@4211	AC METHOD BIAS COND D V_{RM} = 1200V(pk)		I_{RRM}	-	20	mAdc
FORWARD BLOCKING CURRENT	@4206	AC METHOD BIAS COND D V_{DM} = 1200V(pk)		I_{DRM}	-	20	mAdc

DEPT	LOC	SIZE	CODE IDENT NO.	
DRAWN R.A. Weiss 1/9/79		A	89954	283A8357
CHECKED R.A. Weiss 1/11/79		SCALE NONE		SHEET 22

TABLE V (CONT'D)
GROUP C INSPECTION

EXAMINATION OR TEST	# MIL-STD-833 @ MIL-STD-750 METHOD	DETAILS	LTPD	SYMBOL	LIMITS MIN	MAX	UNIT
GATE TRIGGER VOLTAGE AND GATE TRIGGER CURRENT	@ 4221	V_1=5.0 Vdc, R_E=25 OHMS R_L=3.0 OHMS MAX. V_2=6.0 MAX. Vdc		V_{GT} I_{GT}	- -	3 150	Vdc mAdc
SUBGROUP 4			10	-	-	-	-
THERMAL FATIGUE		I_T(RMS/SCR)= 38 AMP 48,000 CYCLES LOWER CASE TEMP.=35°C UPPER CASE TEMP.=75°C		-	-	-	-
ENDPOINTS	@4211	AC METHOD BIAS COND D		I_{RRM}	-	20	mAdc
REVERSE BLOCKING CURRENT FORWARD BLOCKING CURRENT	@ 4206	V_{RM}=1200V(pk) AC METHOD BIAS COND. D V_{DM}=1200V(pk)		I_{DRM}	-	20	mAdc
GATE TRIGGER VOLTAGE AND GATE TRIGGER CURRENT	@4221	V_1=5.0 Vdc R_E=25 OHMS R_L=3.0 OHMS MAX. V_2=6.0 Vdc		V_{GT} I_{GT}	- -	3.0 150	Vdc mAdc

DEPT LOC	SIZE A	CODE IDENT NO. 89954	283A8357
DRAWN R.A. WARGO 1/9/79			
CHECKED R.A. WARGO 1/9/79	SCALE NONE		SHEET 23

DIST TO

PN-501-AF 10-78-8-11 PRINTED IN U.S.A.

TABLE V (CONT'D)
GROUP C INSPECTION

EXAMINATION OR TEST	METHOD	DETAILS	LTPD	SYMBOL	LIMITS MIN	LIMITS MAX	UNIT
PEAK ON-STATE VOLTAGE	@ 4226.1	I_{TM}=200AMP (PK) T_C-25°C, PULSE WIDTH=8.3ms		V_{TM}	-	3.3	VOLTS**
THERMAL RESISTANCE JUNCTION TO BASE	@ 4081	T_2=100°C MAX T_1= 80°C MIN (SEE FIG. 7) I_{F1}=75A MAX I_{F2}=2A		$R_{\theta JC}$	-	.20	°C/W**

** OR ± 25% WHICHEVER IS GREATER

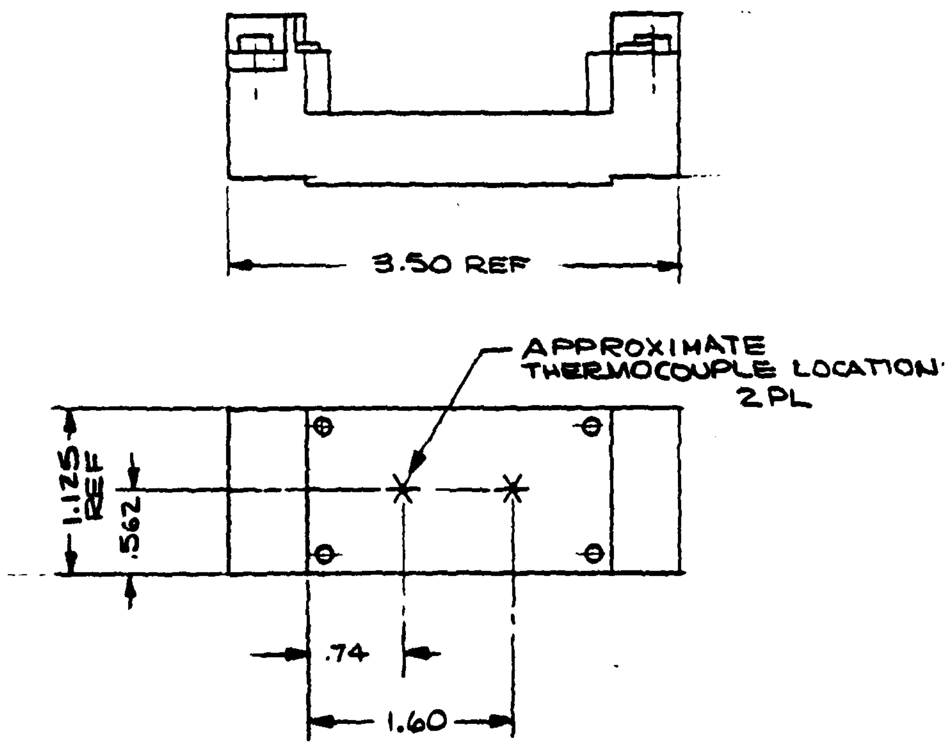
DEPT LOC	SIZE A	CODE IDENT NO. 89954	283A8357
DRAWN R.A. Wargo 9/9/79			
CHECKED K.A. Wargo 9/9/79	SCALE NONE		SHEET 24

DIST TO

FN-505-AF 10-70-D-U PRINTED IN U.S.A.

SIZE		SHEET	REV
A	283A8357	26	B

FIGURE 7



	SIZE	CODE IDENT NO.	
DEPT LOC	A	89954	283A8357
DRAWN R.A. Walsh 1/9/79	SCALE NONE		SHEET 25
CHECKED R.A. Walsh 1/11/79			

APPENDIX B

DUAL SCR POWER MODULE

DUAL SCR POWER MODULE*

John W. Butler, Project Engineer - Aerospace Electrical Systems Programs
Dr. Homer Glascock, Physicist - Corporate Research and Development

General Electric Company
Binghamton, NY

ABSTRACT

Further miniaturization of high-power semiconductor devices utilizing silicon disks larger than 12 mm. requires major innovations to improve the average thermal impedance and surge capability. The high thermal impedance in existing discrete devices is caused mostly by the dry interfaces necessary to provide stress relief.

This paper presents a unique approach to solving the dry interface problem. It will describe a smaller, lighter, electrically isolated dual thyristor module featuring structured copper, solder bonding, polyimide passivation, direct bonded copper on beryllium oxide and a hermetic sealed aluminum case.

The design objectives, applications, package design, fabrication, and test results from 36 modules will be presented.

INTRODUCTION

Present day aircraft require three-phase 400 Hz electrical power. Since aircraft engines run at widely varying speeds, some means must be provided to convert the variable speed to a constant frequency generator output. Most AC aircraft systems in use today employ a hydro-mechanical transmission to maintain constant input speed to a synchronous generator.

With the introduction of the silicon controlled rectifier (SCR) in 1958, a search for a more reliable 400 Hz aircraft power system began. The result electronically converts the variable frequency output of a generator to constant frequency 3 phase 400 Hz power. Such a system was developed using a cycloconverter which converts variable frequency AC into a constant frequency AC with no DC link (VSCF).

*Being developed under AF contract F33615-78-C-2029 with AFAPL at WPAFB.

This electronic conversion process for aircraft systems arose through the development of the SCR. Significant improvements in converter reliability, such as size and weight, are dependent on the continuing development of improved power switching modules containing SCR's.

The successful use of the cycloconverter within the VSCF system has clearly been dependent on the development of the SCR in providing reliable high power switching and control.

The work reported in this paper is presently being conducted under USAF Contract F33615-78-C-2029 for the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The contract, in five phases, calls for the design, fabrication and test of power hydrid modules containing SCR's for a 60 KVA, six phase VSCF system using a rare earth magnet generator.

The program is now complete thru the third phase (1st generation module tests) and is the basis for this paper.

The module features two 18 mm silicon SCR pellets mounted in a hermetically sealed aluminum housing and bonded to an electrically isolated mounting base. Low thermal impedance and mechanical stability are achieved by the use of structured and direct-bond copper.

BACKGROUND (State of the Art)

Since the cycloconverter uses so many SCR's (36), improved reliability, lower cost and weight of these devices would clearly provide a basis for improvements in the cycloconverter.

Recognizing the need for cost, weight and reliability improvements in this thyristor component area, a VSCF oriented power module development program was begun in 1977 to parallel the existing and continuing power module technical development activity of the GE Corporate Research and Development Center.

In addition, late in 1978, the General Electric Co. Aerospace Electrical Systems Programs was awarded a contract to develop and test a hybrid power module for a 60 KVA VSCF system. This 2 1/2 year program involved the selection of a pellet and a detailed module design. This program also involved the analysis of first generation modules, fabrication and test of second generation modules and ultimate test of a complete set of 2nd generation modules in a VSCF system.

PELLET SELECTION, FABRICATION*

The preferred choice of the approaches considered was a dual SCR module in a rectangular hermetically sealed package designed to mount on a chill plate. See Figure 1. The module uses 18 mm diameter chips in a configuration which has a calculated steady-state thermal resistance from base plate to junction of 0.110°C/W. The module uses structured copper and special bonding to achieve this low thermal resistance. The dual SCR module is preferred over a triple thyristor module in several respects, but the most significant is manufacturing simplicity and low weight. It is a very convenient configuration for the VSCF converter and broad application will ultimately permit a significantly lower cost module.

Two major and necessary device processing changes were required to obtain junction assemblies suitable for the package described later in this paper.

The first necessary change involved the use of a new passivation technology which allows temperatures up to 400°C to be applied to a fully passivated device. A polyimide polymer developed for junction passivation is applied to the junction instead of RTV. Fully cured, it can withstand short periods of 400°C which are necessary for solder bonding, a step later done in assembling the power module.

The second necessary process change involves the development of a device metallization scheme which permits solder attachment to structured copper. A photograph of a typical passivated SCR pellet is shown in Figure 2.

ADVANCES IN MATERIALS AND TECHNIQUES FOR POWER SEMICONDUCTOR PACKAGING

During the past several years various materials and techniques have been developed for packaging power devices. These developments permit a given device to be operated at a higher rating or alternately, a device of a smaller size to be operated at a given rating. The two most important materials are structured copper and polyimide-passivation, and the most effective technique is direct bonding of copper to ceramic.

Structured Copper Electrodes

Structured copper was developed in order to remove dry interfaces and thick solder joints from device packages. Dry interfaces, and to a lesser extent solder joints, are both electrically and thermally resistive. In the past, they have proved necessary in power device packages to offset the formidable problem caused by the tremendous difference between the thermal expansion of silicon and all good conductors. For silicon devices to successfully control large amounts of electrical power, contacts which are highly conducting both

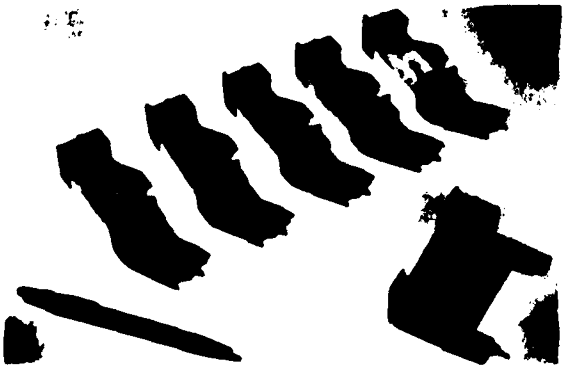


Figure 1 SCR Modules

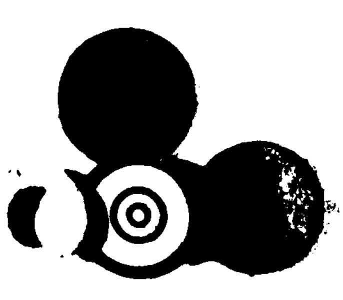


Figure 2 Passivated Silicon Pellet with Structured Copper "Disc" and "Donut"

*SCR Pellets fabricated by Semiconductor Products Department of General Electric Co., Auburn, NY.

electrically and thermally are necessary to prevent overheating of the device. Traditional conductors such as copper and aluminum have thermal expansions of approximately ten times higher than silicon. As a result, expensive tungsten is generally used as the conductor, and even this material, with a substantially closer expansion match, presents serious differential thermal expansion problems when sealing to both sides of a silicon wafer or one side of a larger wafer. Consequently, a tungsten conductor (or slightly lower cost molybdenum) is presently brazed to one side of a large silicon device; the second contact between the silicon and a tungsten or molybdenum washer is dry. These parts are pressed together, between two massive copper electrodes, under hundreds of pounds of force. Differential thermal expansion, however, can still be a problem, for the tungsten or molybdenum washer tends to damage the silicon by scrubbing as the two surfaces shift laterally when the device changes temperature.

The approach to this problem is to fabricate a compliant conductor from a multitude of wires of small diameter. When the ends of the wires are bonded to silicon, each wire is "indexed" to a point on the silicon and, as the structure cools, the wires move independently. Differential thermal expansion occurs across the end of each individual wire which presents no problem. This is illustrated in Figure 3.

Copper as a Thermal Conductor

The achievement of high operating power levels in silicon semiconductor devices is largely dependent upon the ability to effectively remove heat from the silicon. High thermal conductivity heat sinks must be attached to one or, better, two sides of the silicon wafer, to accomplish this. For surge survival the choice of material for the heat sinks depends not only upon its thermal conductivity, but also upon its specific heat and density. A figure of merit for the choice of heat sink material is needed, and this can be obtained from one of the cases described by Carslaw and Jaeger.[1] They described a semi-infinite solid (the heat sink) with a constant flux (F_0) heat source (the silicon wafer) at the surface ($x = 0$) and calculate the temperature at any point in the solid as a function of time. The temperature is needed at the heat source ($x = 0$); this should rise as slowly as possible after the heat source is turned on at $t = 0$.

The expression for the temperature reduces to the simple form

$$T = \frac{2F_o}{K} \left(\frac{kt}{\pi}\right)^{\frac{1}{2}} \text{ at } x = 0,$$

where k is the thermal diffusivity

$$k = \frac{K}{\rho c}$$

where

K is the thermal conductivity of the material

ρ is its density

c is its specific heat.

Thus the temperature rises as the square root of time, and the complete expression is

$$T = \frac{2F_o}{\sqrt{\pi}} \frac{\sqrt{t}}{\sqrt{K \rho c}}$$

Thus, for surge survival, the quantity $1/\sqrt{K \rho c}$ should be as small as possible, and this is the needed figure of merit for the heat sink material. This figure has been evaluated for a number of materials that might be used for heat sinks and the list is given in Table 1.[2] The results are surprising because many would intuitively pick silver as the first choice. Copper is, however, the best material to use; this is fortunate because of its lower cost. The disadvantage of its higher

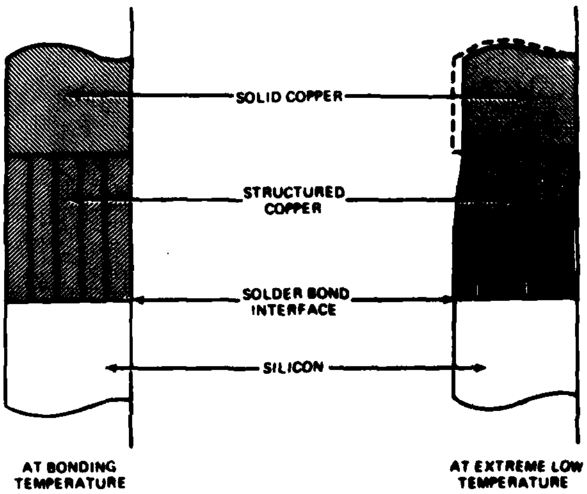


Figure 3. Illustration of Structured Copper

[1] Carslaw, H. S. and Jaeger, J. C. "Conduction of Heat in Solids" (Oxford Univ. Press) 2nd ed., Page 75 (1959)

[2] Private communication with Harold F. Webster.

thermal expansion coefficient with respect to silicon is overcome by fabricating it in the form of structured copper.

TABLE 1

$1/\sqrt{K \rho c}$ for various metals, showing that copper is the best heat sink for current surges

Cu	1.135
Ag	1.304
Au	1.539
Be	1.665
A	1.771
W	1.836
Mo	2.155
Ni	2.745
Ta	3.588
Nb	4.031
Pb	5.854
Ti	6.611
Zr	7.669

Structured Copper as a Stress Relief Medium

When structured copper is attached to a material having a lower thermal expansion coefficient and the sandwich is then cooled to a lower temperature, the tensile and compressive stresses in the sandwich will be less than the use of solid copper would have produced. These results are due to the fact that neighboring copper wires separate from each other, and the normal tensile stress which would appear in the copper is reduced to a low value. Thus, the equal compressive stress in the low expansion member is also reduced. If, however, a large fraction of the wires stick together, the copper will not pull apart under tension, and will fail to provide the needed stress relief. In producing the structured copper it is therefore important to use processes which do not make the wires attach to one another.

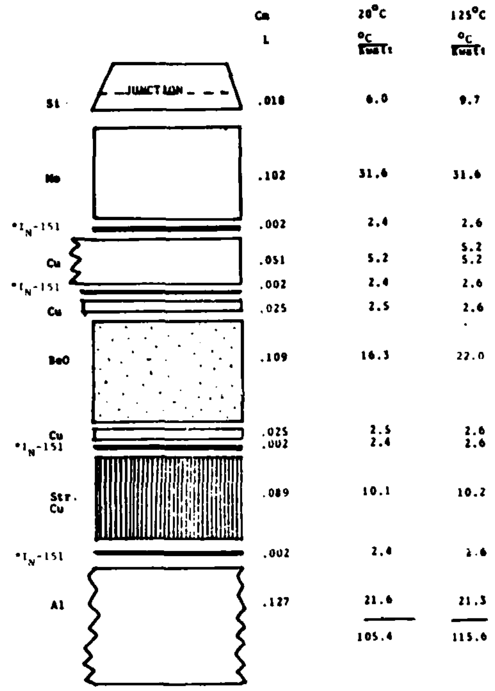
Fabrication of Structured Copper

In order to fabricate structured copper, a copper tube or pipe must be filled with thousands of parallel copper wires. After the wires in the pipe have been compacted into a rod, slices can be made. The pipe wall holds the wires together. No problems arise with braze or solder penetrating between the wires in these structures except when large amounts of flux are allowed to flow between the wires.

Structured copper bodies of various geometries are used in several different applications. Due to the fragile nature of this material when the holding ring is removed, necessary techniques have been developed to hold the closely packed wire together prior to sealing to a device. One method, which has been used extensively, is to flow solder over one or both faces prior to removing the holding ring. Following solder flow, the structured copper pieces can be punched from the disk. Figure 2 shows the structured copper shapes in the module fabrication.

Cooling Considerations

A high power semiconductor device must have low thermal resistance from the silicon junction into the coolant for both steady state and surge conditions. For good steady state operation, high thermal conductivity materials and interfaces must be used throughout the thermal path. For surge operations in which the device is subjected to a single .008 second pulse of very large amplitude, the requirements are more complex because heat is removed by conduction and storage within the material surrounding the silicon. As was described earlier, materials should be used which have the highest values of the product of thermal conductivity, specific heat, and density. The presence of dry interfaces in conventional power semiconductor packages exacts a significant toll in device performance. A voltage drop occurs across the dry interface so that heat is dissipated at that location when large currents are drawn. The magnitude of this thermal resistance is highly dependent on the surface conditions and clamping force. Even under rather ideal conditions with very large clamping forces, a single dry interface will have a thermal resistance equivalent to 120 mils of copper, 65 mils of aluminum or 40 mils of molybdenum. For surge conditions, the heat does not travel far from the silicon, and the materials on each side of the silicon wafer within a distance of about 60 mils determine the surge performance. A dry interface within this region is especially harmful, because it adds both electrical and thermal resistance, and this is the reason that 35 mils of structured copper have been attached to the cathode surface in the design described here. Evaluation of surge performance and steady state performance is complex, and a computer program has been developed which is usable with various geometries and materials. Evaluation of steady state performance can be done with a single thermal resistance model which is utilized to determine the thermal resistance of each layer and interface; these values are then added in series and parallel combinations to yield the total resistance from silicon to the coolant. Figure 4 summarizes these calculations where lengths (L) are shown in centimeters. The greatest uncertainty in this calculation is the evaluation of the interface resistance, which depends upon flatness, pressure and the presence of surface films.



*Registered trademark of the Indium Corporation of America

Figure 4. Thermal Resistance Model

Direct Bonded Copper

For efficient cooling from the bottom of the power pellet, it becomes necessary to have a material present in the package which is a good thermal conductor, as well as a good insulator. This is a requirement for the power hybrid proposed here, in order to electrically insulate the SCR's from each other and the base plate. To ensure efficient cooling of the SCR's, however, a good thermal contact is also required. Normally, the material used for such an application is beryllia, which is metallized by thick film techniques. Thick film metallization techniques are, however, inadequate here for three reasons. First, the sheet resistivity of thick film copper or noble metal films is too high to carry large currents without significant IR drop; this would add to undesirable power dissipation. Secondly, the thick film-to-beryllia adhesion mechanism requires the presence of at least some quantity of a glassy phase, which limits the thermal conductivity through the beryllia. Thirdly, the adhesion of the thick film to beryllia is generally too poor to support massive current tabs necessary in power devices.

These disadvantages of thick film metallization can be overcome by the use of "Direct Bonded Copper", developed at General Electric Company and, at present, commercially available from GE in power modules and discrete power devices. For this metallizing technique, the beryllia insulator is clad with a copper foil which can be in excess of 10 mils thick, without an intermediary "glue" layer. The metallizing is done through the use of the copper oxide eutectic at 1065°C, using a single pass through a commercial tunnel oven in a factory grade nitrogen atmosphere. This method gives a bond of the highest thermal conductance, with a bond strength in excess of 20,000 psi, and allows the attachment of a contact with negligible IR drop, even for high currents. Thermal cycling has also indicated exceptionally high bond integrity. In addition, the bond is hermetic.

MODULE DESIGN/DESCRIPTION

Subassembly Design and Fabrication

Each subassembly is fabricated, as illustrated in the exploded view of Figure 5, using parts as shown in Figure 6, which results in the final assembly, as shown in Figure 7. Parts are stacked and clamped with gentle pressure using 92.5% Pb, 2.5% Ag, 5% Sn solder preforms and a non-active flux between the interfaces. Reflow takes place in a furnace with dry nitrogen gas.

Hermetic Module Assembly

This procedure is completed in two operations; first the feed-through terminals, and then both subassemblies and all internal interconnections,

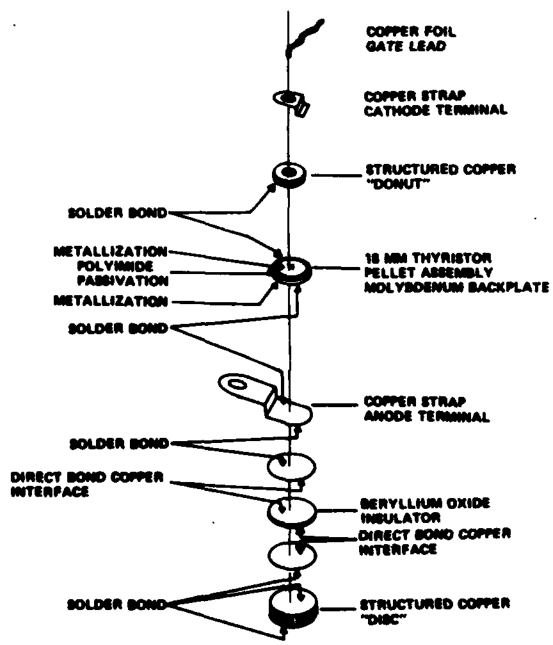


Figure 5. Exploded View - Subassembly Fabrication

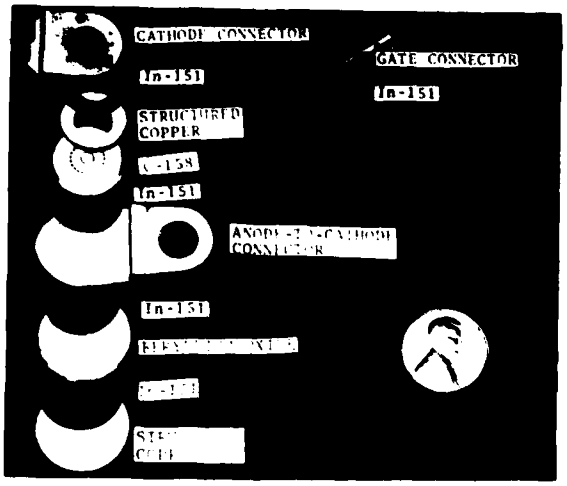


Figure 6. Subassembly Parts

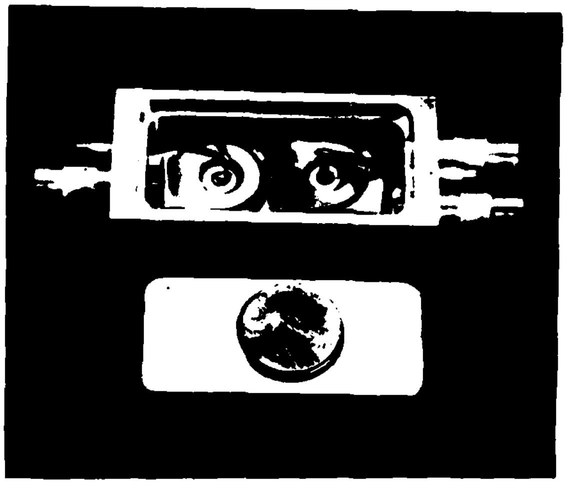


Figure 8. Module Assembly Prior to Sealing

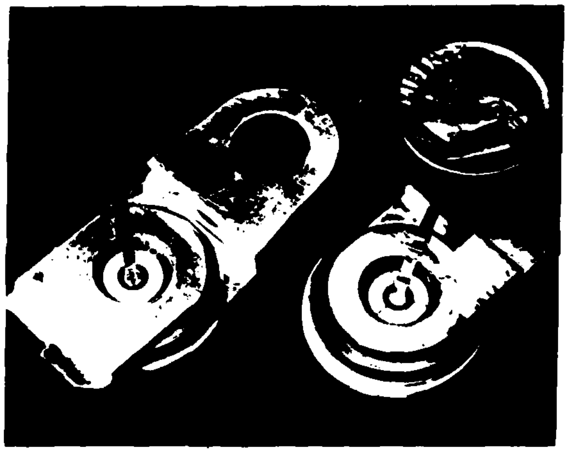


Figure 7. Complete Subassemblies

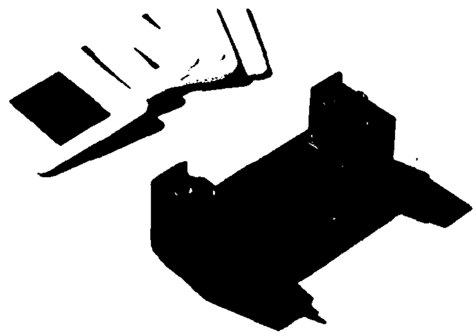


Figure 9. Completed Module Assembly

are installed in the tin plated aluminum housing, using fluxed solder preforms in a dry nitrogen furnace. The assembly appears as shown in Figure 8. A coating of RTV is next applied to all internal parts and is cured prior to sealing on the lid with 60% Sn - 40% Pb solder in a dry nitrogen furnace.

Final Assembly

All external connections between the feed-through terminals and the external screw connections are completed, and the module ends are potted with a filled epoxy compound as shown in Figure 9.

Module Test Program

The first 36 completed modules were divided into three groups of 12, each by statistical methods, and the evaluation program, as described in Table 2, was conducted.

Most test sequences are self-explanatory, but a short explanation of some might be helpful to those unfamiliar with the details.

The electrical test sequence includes measurements of on-state voltage, peak reverse voltage, peak off-state voltage, gate trigger characteristics, turn off time, and dv/dt at appropriate, ambient temperatures.

The burn-in test involves ten temperature cycles from $-55^{\circ}C$ to $+150^{\circ}C$ followed by the application of a sine wave voltage at the peak repetitive off-state level (1,200 V) for 96 hours in an ambient of $+125^{\circ}C$.

TABLE 2

SEQ. NO.	DESCRIPTION	GROUP I	GROUP II	GROUP III	COMMENTS
1	Physical Dimensions	X	X	X	(1)
2	Internal Visual	X	X	X	(1)
3	Electrical	X	X	X	(1)
4	External Visual	X	X	X	(3)
5	Insulation Resistance	X	X	X	(3)
6	Seal	X	X	X	(3)
7	Burn-In	X	X	X	(3)
7A	Electrical	X	X	X	(3)
7B	Seal	X	X	X	(3)
8	Barometric Pressure Reduced	X			(3)
8A	Seal	X			(3)
9	Immersion		X		(3) (4)
10	Salt Atmosphere			X	(3)
11	Thermal Characteristic	X			(3) (4)
12	Temperature Cycling		X		(3)
13	Thermal Shock			X	(3)
13A	Electrical	X	X	X	(3)
13B	Seal	X	X	X	(3)
14	Mechanical Shock	X			(3)
15	Vibration Fatigue		X		(3)
15A	Electrical	X	X		(3)
15B	Seal	X	X		(3)
16	Failure Analysis	AR	AR	AR	(2)

COMMENTS

(1) Tests associated with sequence Nos. 1-3 may be accomplished prior to hermetic sealing.

(2) Device failures resulting from tests with sequence number 3, 5 and 7-15 shall be analyzed by method 5003 of MIL-STD-883A.

(3) A detailed history of each of the specialized power hybrid devices shall be maintained as part of the test program.

(4) One of the devices successfully passing the immersion test shall be dissected per method 2013 of MIL-STD-883A.

The seal tests were performed using a 100°C glycol bubble test, since gas entrapment between the aluminum-epoxy interface prevented use of the prescribed test.

The immersion test consists of 5 cycles of immersion in a hot bath of fresh tap water @ 65°C, followed by immersion in a cold water bath at 25°C.

The thermal characteristics are tests that measure the thermal resistance, SCR junction to base plate.

Devices are temperature-cycled between -55°C and +150°C for 10 cycles with a 30-minute dwell at each temperature extreme.

The thermal shock test consits of 15 cycles immersion in a suitable liquid at 100°C, followed by immersion in a suitable liquid at 0°C, with a maximum transfer time of 10 seconds.

The mechanical shock tests involve subjecting the device to 5 shock pulses of 30g for 11 millisecond duration in each of six direction. (+ and - direction of each of 3 mutually perpendicular.)

Vibration fatigue requires subjecting each device to a 60 Hz vibration of 5g's for 32 hours in each of three mutually perpendicular planes.

Test Results

The initial results on all modules were generally very satisfactory. A few modules exhibited higher than expected thermal resistance, seal leaks,

failure to block voltage or trigger properly at $-55^{\circ}C$.

COMMENTS

Subsequent analysis of the failures revealed that the use of an SCR pellet designed to meet higher blocking voltage at the $-55^{\circ}C$, along with improvements in module manufacturing methods, tools and screening tests would essentially eliminate all failures experienced during the testing phase.

CONCLUSIONS

Further miniaturization of high-power semiconductor devices, utilizing silicon discs larger than 12 mm, requires major innovations to improve the average thermal impedance and surge capability. The high thermal impedance in existing discrete devices is mostly caused by the dry interfaces necessary to provide stress relief.

This paper described a unique approach to solving the dry interface problem. The device is a smaller, lighter, electrically isolated dual thyristor module.

The advantages of utilizing structured copper and direct bond copper, along with an aluminum enclosure, for dual SCR modules using large silicon pellets, was analyzed and proven experimentally.

Detailed design, fabrication, and test results were described.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of C. Neugebauer, H. Webster and J. Burgess of General Electric Corporate Research and Development Center and M. Sopchak, L. Ahern, P. Olski, R. Dyer of General Electric Solid State Applications Operation.

They also wish to thank Mr. W. U. Borger, Air Force Program Manager for his program guidance and Ms. Terri L. Butler for her helpful grammatical suggestions.

LIST OF TABLES

LIST OF ILLUSTRATIONS

APPENDIX C

PHASE III HYBRID TEST PLAN

APPENDIX C

PHASE III TEST PLAN (MODIFIED)

SEQ. NO.	DESCRIPTION	METHOD-HYBRID POWER SPEC 283A8357	GROUP I	GROUP II	GROUP III	COMMENTS
1	Physical Dimensions	Table V Group C.1	X	X	X	(1)
2	Internal Visual	Para. 4.5	X	X	X	(1) (4)
3	Electrical	Para. 4.4	X	X	X	(1)
4	External Visual	Table V Group B.1	X	X	X	(3)
5	Insulation Resistance	Table V Group B.1	X	X	X	(3)
6	Seal	Table I Screening Tests	X	X	X	(3)
7	Burn-in	Table I Screening	X	X	X	(3) (4)
7A	Electrical	Para. 3.2 except Table IV	X	X	X	(3)
7B	Seal	Table I Screening Tests	X	X	X	(3)
8	Barometric Pressure, Reduced	Table V Group C-2	X			(3)
8A	Seal	Table I Screening Tests	X			(3)
9	Immersion	Method 1002 MIL-STD-883A		X		(3) (5)
10	Salt Atmosphere	Table V Group C-2			X	(3)
11	Thermal Characteristics	Table V Group B.4	X			(3) (4)
12	Temperature Cycling	Table V Group B. 2		X		(3)
13	Thermal Shock	Table V Group B. 2			X	(3)

APPENDIX C (CONT.)

PHASE III TEST PLAN (MODIFIED)

SEQ. NO.	DESCRIPTION	METHOD-HYBRID POWER SPEC 283A8357	GROUP I	GROUP II	GROUP III	COMMENTS
13A	Electrical	Table V Group B.2, End Points	X	X	X	(3)
13B	Seal	Table I Screening Tests	X	X	X	(3)
14	Mechanical Shock	Table V Group C.1	X			(3)
15	Vibration Fatigue	Table V Group C.1		X		(3)
15A	Electrical	Table V Group C.1 End Points	X	X		(3)
15B	Seal	Table I Screening Tests	X	X		(3)
16	Failure Analysis	Method 5003 MIL-STD-883A	AR	AR	AR	(2)

COMMENTS

(1) Tests associated with sequence nos. 1-3 may be accomplished prior to hermetic sealing.

(2) Device failures resulting from tests with sequence numbers 3, 5 and 7-15 shall be analyzed by method 5003 of MIL-STD-883A.

(3) A detailed history of each of the specialized power hybrid devices shall be maintained as part of the test program.

(4) Test method used is equivalent to contractual requirement and conforms more nearly to standard practices for power semi-conductor devices.

(5) One of the devices successfully passing the immersion test shall be dissected per method 2013 of MIL-STD-883A.

APPENDIX D

FIRST GENERATION HYBRID TEST REPORT

REPORT ON PHASE III TEST RESULTS

1.0 INTRODUCTION

1.1 TEST PLAN

The test plan for the first generation hybrid modules is Table IA, IB, and IC which is based on Table I of the contract. References are made to applicable sections of the Hybrid Module Specification, Drawing 283A8357.

1.2 TEST GROUPS

A quantity of 37 modules were fabricated. These were divided into three groups of 12 each plus one extra. The selection of the module serial numbers to make up the three groups was made with the aid of a random number table. Figure 1 is a photograph of one of the modules.

2.0 SUMMARY OF RESULTS

2.1 OVERALL SUMMARY

Nine of the thirty-six modules tested passed all tests with the exception of one electrical test at low temperature which will be discussed later. (Page 66) Following completion of the 100% screening tests, through Sequence 7, twenty-one of the thirty-six modules exhibited no significant deterioration for test Sequences 8 through 15. Significant accomplishments of this program include (a) good temperature cycling performance (b) no open internal electrical connections and (c) no significant external damage for modules fabricated in accordance with the documented process.

2.2 SUMMARY FOR SEQUENCES 1 THROUGH 7

The results for test sequences 1 through 7 are (Page 78) summarized in Table II. Planned corrective action for problems found is also shown. These items will be discussed in depth in Section 4.0 of this report. Table II shows that the most significant problems are related to SCR voltage capability with six SCR's downgraded at -55°C and six SCR's downgraded as a result of the 96 hour blocking voltage screen (burn-in) test.

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Figure 1 - Dual SCR Hybrid Module

2.2 SUMMARY FOR SEQUENCES 1 THROUGH 7 (continued)

The following paragraphs provide additional details on the individual test sequences.

2.2.1 Sequence 1 - Physical Dimensions

Detailed measurements of all dimensions were made on all modules, including mounting dimensions, power/gate screw-terminal dimensions, surface insulating barrier dimensions, and overall dimensions. Weight was also measured on each module. Weights ranged from 105.3 grams to 113.5 grams. The mean weight was 108.8 grams.

Many measurements were within the hybrid module spec. requirements, but others were outside the allowable tolerances. In every case, those which fell outside the limits, reflect the laboratory methods and tools used to fabricate the parts rather than any design deficiency. Subsequent generations of modules will be able to meet all critical dimensions by improved methods and tooling.

Therefore, no detailed summary or analysis of data will be included in this report.

2.2.2 Sequence 2 - Internal Visual Inspection

All modules were given a careful visual inspection prior to lid sealing. Magnified photos were taken of each module. No defects were observed. A detailed instruction was written and used for modules with serial numbers 50 and higher. No defects were observed. A copy of the inspection criteria and inspection form is included in Section 5.0, (Page 95). Figure 2 shows photographs of internal construction for modules No. 58 and No. 59. (Page 65)

2.2.3 Sequence 3 - Electrical Tests

Measurements of electrical device characteristics were made on each SCR in each module per conditions and limits defined in the hybrid specification. The tests performed are those detailed in Paragraph 4.4 of 283A8357, Group A Inspection with two exceptions:

1. At 125^{o}C,a dv/dt test was performed at 1200 volts peak in addition to the specified test at 700 volts peak.

2. At -55^{o}C,holding current was not measured.

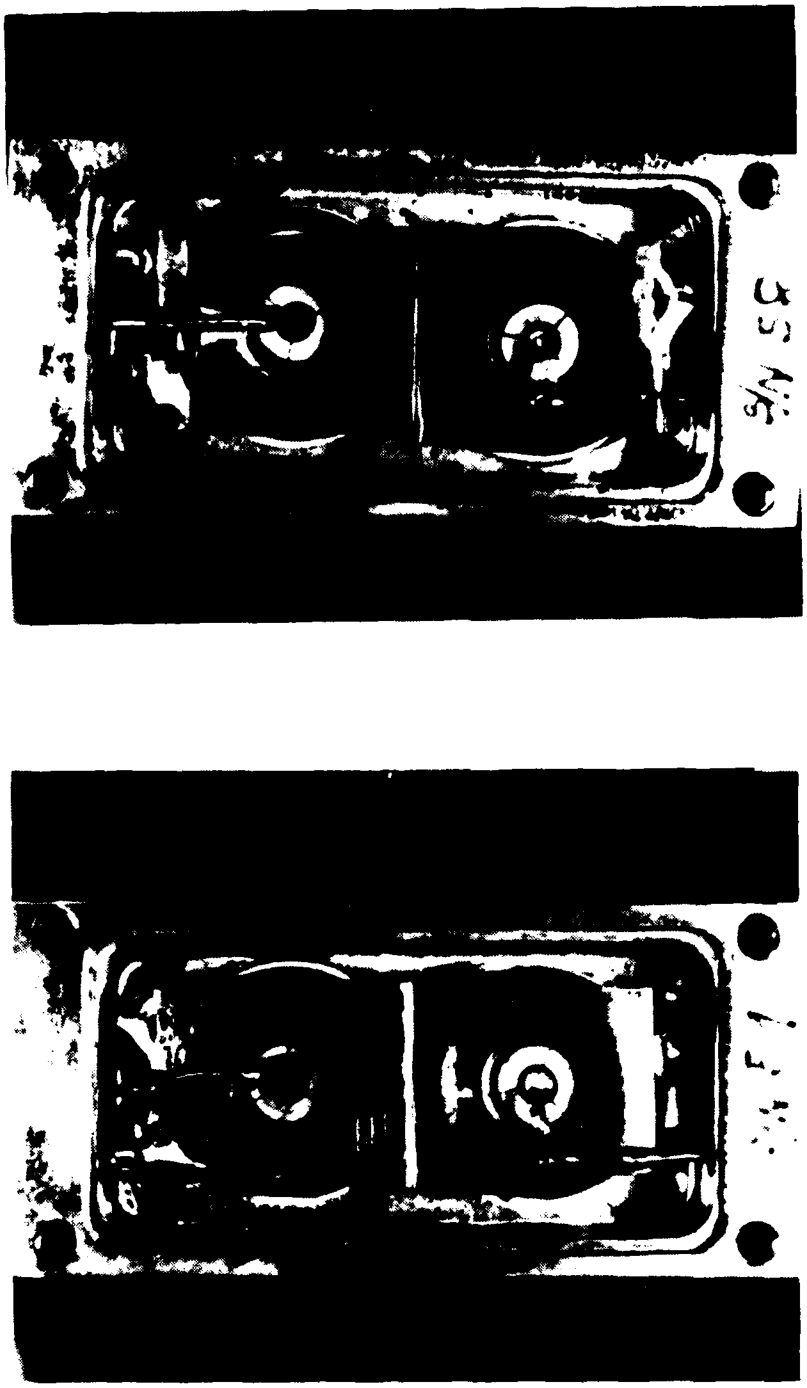


Figure 2 - Photographs of Internal Construction

since no -55°C test limit is given in the specification.

The results of the electrical testing are summarized in Table III (P. 79). The special C-158 SCR pellets procured for Phase II module fabrication were known to be marginal to the 1200 volt repetitive voltage requirement and were not tested to the 1400 volt non-repetitive voltage requirement by the vendor. Other than that electrical test results to the hybrid spec. limits were very good except for two tests:

1. The -55°C gate trigger current and gate trigger voltage limits proved to be too tight. Nine SCR's did not meet these limits.

2. The turn-on voltage limit of 8 volts proved to be too tight with forty-nine rejects. A limit of 11 volts would have resulted in only one reject (which was also a reject to the on-state voltage test).

Table VI (P. 84) presents the Sequence 3 test results in detail for each module and SCR. Table VI is referenced in Section 3.0, Detailed Module History.

2.2.4 Sequence 4 - External Visual Inspection

All modules were subjected to an external visual inspection. A sample of the inspection form and inspection criteria is included in Section 5.0, (P. 94) Appendix. Many modules exhibited damaged partitions between terminals because of problems with the molds used for casting. Other problems included insufficient epoxy around terminals and poor marking quality. All of these problems will be addressed and easily corrected during Phase IV of the project.

2.2.5 Sequence 5 - Insulation Resistance

Two of the thirty-six modules tested exhibited very low impedance from terminals to base plate. These were modules Serial No. 1 and 13. Module No. 13 was opened and one copper cathode strap was found to be in direct contact with the aluminum case. This defect should have been detected at internal visual inspection.

2.2.6 Sequence 6 - Seal Test

It was found that leak test methods employing pressure bomb prior to leak detection gave unreliable results

because of entrapment of the pressure bomb medium in the epoxy-aluminum interfaces. Helium leak test was abandoned for this reason. Modules with serial numbers 1 to 21 were pressure bombed in Freon TF and then immersed in 60°C de-ionized water for leak detection. All bubbled from the ends but no bubbles were observed around the lid seal. The remaining modules were not pressure bombed but were immersed in 100°C glycol. No leakers were found. The sensitivity of the glycol bubble test is estimated to be about 10^{-4} atm. cc/second versus the specified value of $5x10^{-6}$ atm. cc/sec.

Prior to epoxy encapsulation of the ends, modules with serial numbers 50 through 68 were each checked twice using helium leak test. First the glass to metal feed-thrus were checked and after lid seal the entire module was checked. No leakers were found.

2.2.7 Sequence 7 - Screening Tests

Screening tests were performed on all modules per Table IA. Following high temperature storage and temperature cycling steps of the sequence, the modules were re-measured electrically to assess the effects of these stresses on device characteristics. Module 4 SCR 2 was found to have an open gate. Module 11 SCR 2 downgraded in off-state voltage capability to 600 volts. No other significant degradation took place.

The modules were then subjected to 96 hours blocking voltage test at 125°C temperature with 1200 volts peak full sine wave applied. A total of twenty SCR's blew two fuses. (After an SCR blew one fuse, the test position was re-fused to ascertain that the SCR under test was at fault rather than the test position or fuse). Six of the SCR's exhibited downgraded voltage capability when measured electrically following the 96 hour blocking test. Ten of the twenty SCRs had been expected to fail blocking because of low voltage capability prior to this test.

Seal test conducted following blocking revealed two lid leakers, modules 4 and 16. It is concluded that the temperature cycle test was responsible for this. Later it was found that module 4 became a leaker because excessive RTV inside the cavity forced up the lid and broke its solder seal. The excess of RTV was also responsible for the open gate of Module 4 SCR 2. When the RTV expanded, it pulled the internal gate lead off the silicon disc.

2.3 SUMMARY FOR SEQUENCES 8 THROUGH 15

The results for test sequences 8 through 15 are summarized in Table IV (P. 80). Planned corrective action for problems found is also shown. These items will be discussed in depth in Section 4.0 of this report. Table IV shows that reduced barometric pressure resulted in reduced voltage capability for three modules. It was concluded that these modules were actually case seal leakers since voltage capability was within limits at sea level pressure either before or after the 30 mm Hg test. Not only must seal leaks be eliminated in Phase IV but also an effective leak test method for completed modules must be developed. Another area for Phase IV improvement is higher than expected thermal resistance on half of the modules measured. Steps will be taken in Phase IV to greatly improve the quality of all internally bonded surfaces.

The following paragraphs provide additional details on the individual test sequences.

2.3.1 Sequence 8 - Reduced Barometric Pressure Test

The reduced barometric pressure test, conducted at a pressure of 30 mm mercury, resulted in reduced voltage capability of four SCR's in three modules. These SCR's were capable of blocking 1200 volts peak both before and after the reduced barometric pressure test. One of these, module No. 3, was examined internally after lid removal and it was found that excessive solder from the lid seal operation ran down the inside of the case. Whether this contributed to voltage breakdown or not is not certain since the module case was not connected to the power supply. The other two modules, numbers 50 and 62 had no obvious defects.

Since these three modules only exhibited reduced voltage capability at reduced barometric pressure, it is concluded that they were undetected case leakers on seal test.

2.3.2 Sequence 9 - Immersion Test

This test was conducted using tap water baths at 65°C and 25°C. The only external effect noted was that some of the modules showed discoloration of the black paint on the epoxy following this test. Module number 13 was examined internally after completion of all tests and no evidence of corrosion or water damage was evident. Seal test, conducted after the immersion test followed

by Sequence 12 temperature cycling, did not detect case leaks in any of the twelve modules.

2.3.3 Sequence 10 - Salt Atmosphere

Following completion of the 24 hour duration salt atmosphere test the modules were examined for exterior defects. It was found that four modules showed peeling and flaking of the plating. Four others showed very minor pitting of the aluminum case. Adequately controlled plating process on aluminum surface will eliminate this problem.

2.3.4 Sequence 11 - Thermal Measurements

Thermal measurements consisted of thermal resistance measurements, SCR junction to the underside of the module base plate, for each individual SCR in the twelve module sub-group. This test was performed electrically by the conventional method using a temperature sensitive device parameter calibrated to SCR junction temperature. The thermal resistance values obtained in this manner were all higher than the module spec. value of 0.2 degrees C per watt. The center of the distribution occurred at 0.5°C per watt. Since it was well known beforehand that the conventional method produces unreliable results on SCR's of this type and size, some modules selected for failure analysis for various reasons, were measured for thermal resistance after lid removal by direct temperature measurement of the silicon surface. Of twelve SCR's tested, six measured below 0.2°C per watt and six were still above spec. The results obtained on SCR's measured by both methods are given in Table VIII, (P. 90) Module Failure Analysis. The accurate measurement of thermal resistance will not be a problem in Phase IV since 100% of the modules will be measured prior to lid seal using the temperature probe method. Work will also be done to improve thermal resistance by improving the quality of all internal bonded surfaces.

2.3.5 Sequence 12 - Temperature Cycling

Ten temperature cycles, -55°C to +150°C, produced no significant degradation of SCR electrical characteristics. No case leaks were detected at seal test following this test.

2.3.6 Sequence 13 - Thermal Shock

The thermal shock test, consisting of 15 cycles of immersion in 100°C and 0°C water resulted in significant downgrading of SCR blocking voltage

capability on eight SCR's in five modules. Following completion of the end point tests, the twelve modules were subjected to a 24 hour bake at 125°C. Re-submission to the end point tests resulted in the recovery of several modules so that the final results showed that thermal shock had caused three SCR's in two modules to downgrade. Although seal test following the thermal shock test did not indicate any case leakers, it is suspected that some modules might be undetected seal leakers.

2.3.7 Sequence 14 - Mechanical Shock

The 30G, 11 millisecond shock test did not produce any noticeable physical or electrical characteristic changes. With the exception of modules 4 and 16 which were identified as leakers prior to this test, seal test following shock did not produce any additional case leaks.

2.3.8 Sequence 15 - Vibration Test

The 96 hour, 5G vibration fatigue test resulted in significant degradation of blocking voltage capability on one module (No. 2). In addition, two modules (numbers 17 and 66) failed seal test following vibration. Redesign of internal terminal straps will reduce stresses.

3.0 DETAILED HISTORIES OF INDIVIDUAL MODULES

Tables V through VII (Pp. 81 thru 89) provide a detailed history of each module through all test sequences. The history is presented for each of the three test groups of 12 modules each. For each group there are three charts: (a) one for Sequences 1-7 (b) one for Sequences 8-15 and (c) one providing additional detail on the Sequence 3 electrical tests. The detailed history tables provide step-by-step test results for each individual module whereas the summary tables discussed previously emphasize performance to each test.

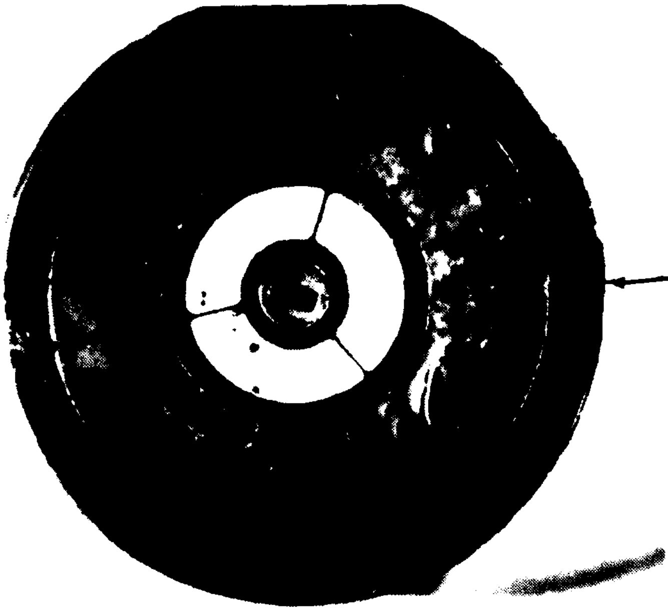
4.0 FAILURE ANALYSIS AND PLANS FOR CORRECTIVE ACTION

A total of eleven modules were selected for failure analysis based on review of the various types of defects recorded. The modules selected have provided sufficient information to correct module problems noted. The detailed results are presented in Table (Pp. 90-92) VIII. The various defects found can be categorized into four principal categories:

	Category	Primary Cause
1.	Downgraded voltage capability	Cracked silicon or moly
2.	High thermal resistance	Poor bonding of internal joints
3.	Reduced barometric pressure	Case seal leaks
4.	Isolation and open gate rejects	Poor inspection and/or process control

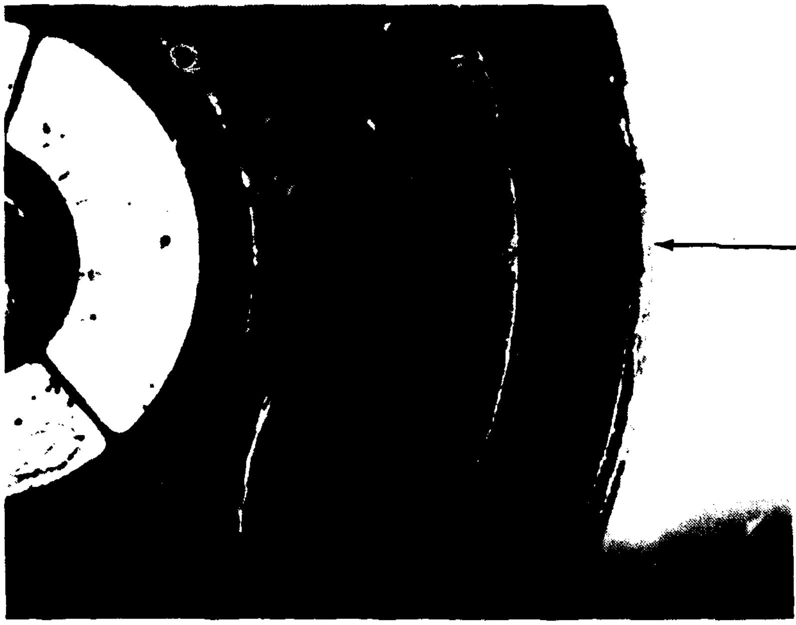
Figures 3 through 6 (Pp. 72-74) inclusive are photographs of dis-assembled modules illustrating most of the above mentioned defects.

Plans have been formulated to take corrective action in Phase IV. These plans are listed in Table IX. (P. 93) Items 6 through 9 are aimed at simplifying assembly as well as at correcting known problems. The actions planned are expected to eliminate essentially all of the reasons for failures and rejects found during Phase III.



TOP VIEW

LOCATION OF CRACK



MAGNIFIED VIEW

LOCATION OF CRACK

Figure 3 - SCR Silicon Sub-assembly
Showing Radial Crack

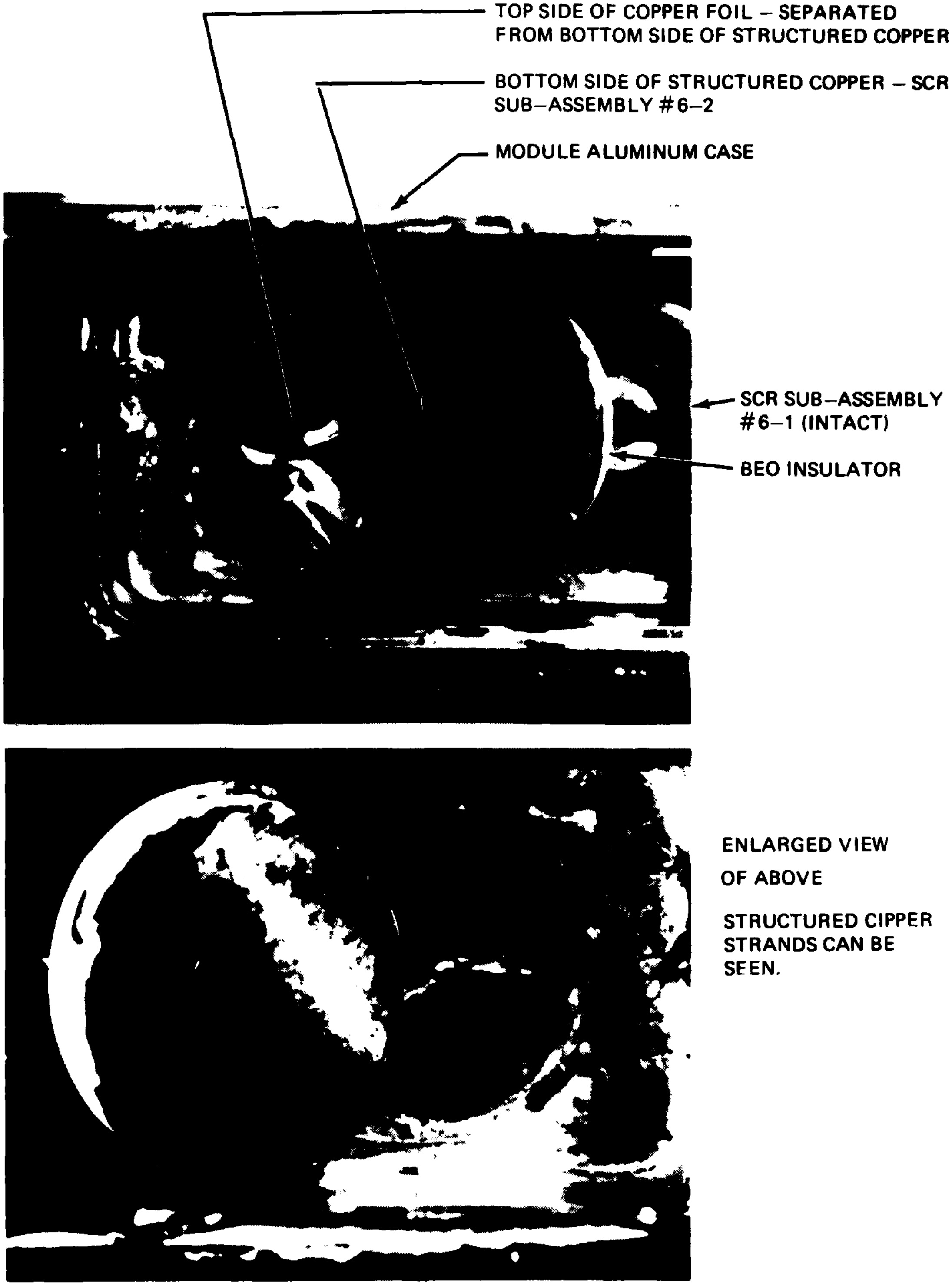


Figure 4 - Foil Separation From Structured Copper Module No. 6-2 - High Thermal Resistance

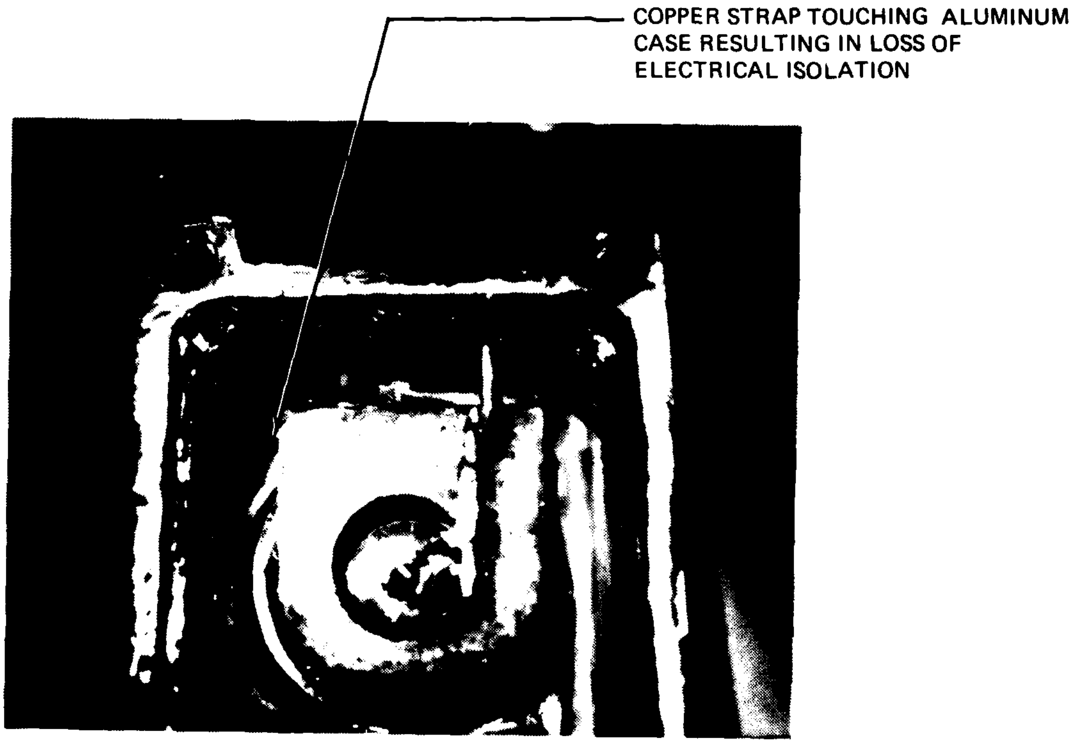


Figure 5 - Module No. 13

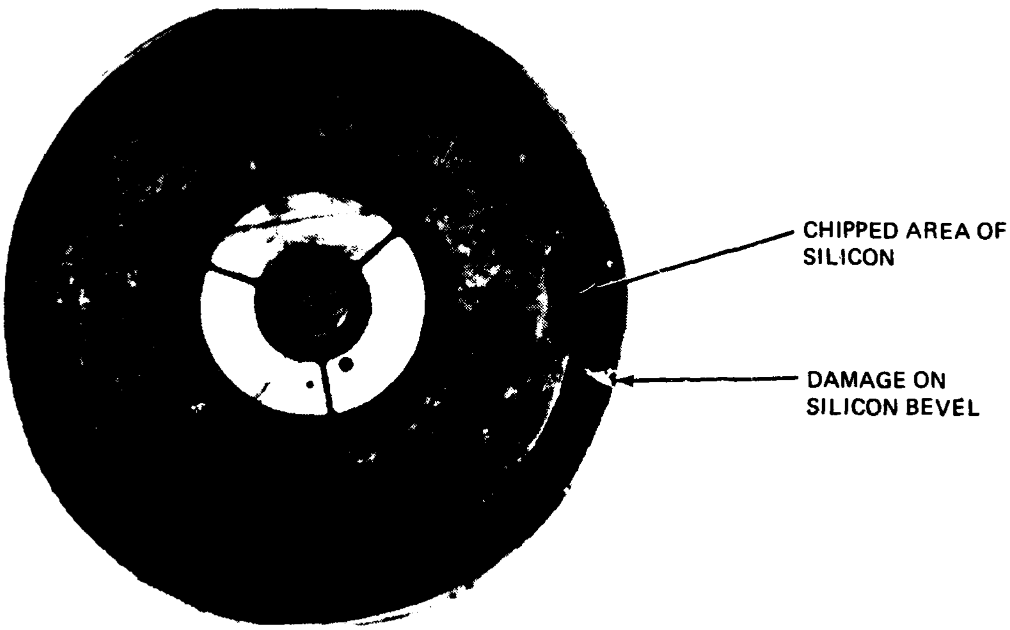


Figure 6 - SCR Sub-assembly From Module No. 6-2

TABLE IA

PHASE III TEST PLAN (MODIFIED)

SEQ. NO.	DESCRIPTION	METHOD-HYBRID POWER SPEC 283A8357	GROUP I	GROUP II	GROUP III	COMMENTS
1	PHYSICAL DIMENSIONS	TABLE V GROUP C.1	X	X	X	(1)
2	INTERNAL VISUAL	PARA. 4.5	X	X	X	(1) (4)
3	ELECTRICAL	PARA. 4.4	X	X	X	(1)
4	EXTERNAL VISUAL	TABLE V GROUP B.1	X	X	X	(3)
5	INSULATION RESISTANCE	TABLE V GROUP B.1	X	X	X	(3)
6	SEAL	TABLE I SCREENING TESTS	X	X	X	(3)
7	BURN-IN	TABLE I SCREENING	X	X	X	(3) (4)
7A	ELECTRICAL	PARA. 3.2 EXCEPT TABLE IV	X	X	X	(3)
7B	SEAL	TABLE I SCREENING TESTS	X	X	X	(3)
8	BAROMETRIC PRESSURE, REDUCED	TABLE V GROUP C-2	X			(3)
8A	SEAL	TABLE I SCREENING TESTS	X			(3)
9	IMMERSION	METHOD 1002 MIL-STD-883A		X		(3) (5)
10	SALT ATMOSPHERE	TABLE V GROUP C-2			X	(3)

TABLE IB

PHASE III TEST PLAN (MODIFIED)

SEQ. NO.	DESCRIPTION	METHOD-HYBRID POWER SPEC 283A8357	GROUP I	GROUP II	GROUP III	COMMENTS
11	THERMAL CHARACTERISTICS	TABLE V GROUP B.4	X			(3) (4)
12	TEMPERATURE CYCLING	TABLE V GROUP B.2		X		(3)
13	THERMAL SHOCK	TABLE V GROUP B.2			X	(3)
13A	ELECTRICAL	TABLE V GROUP B.2, END POINTS	X	X	X	(3)
13B	SEAL	TABLE I SCREENING TESTS	X	X	X	(3)
14	MECHANICAL SHOCK	TABLE V GROUP C.1	X			(3)
15	VIBRATION FATIGUE	TABLE V GROUP C.1		X		(3)
15A	ELECTRICAL	TABLE V GROUP C.1 ENDPOINTS	X	X		(3)
15B	SEAL	TABLE I SCREENING TESTS	X	X		(3)
16	FAILURE ANALYSIS	METHOD 5003 MIL-STD-883A	AR	AR	AR	(2)

TABLE IC

COMMENTS

(1) TESTS ASSOCIATED WITH SEQUENCE NOS. 1-3 MAY BE ACCOMPLISHED PRIOR TO HERMETIC SEALING.

(2) DEVICE FAILURES RESULTING FROM TESTS WITH SEQUENCE NUMBERS 3, 5 AND 7-15 SHALL BE ANALYZED BY METHOD 5003 OF MIL-STD-883A.

(3) A DETAILED HISTORY OF EACH OF THE SPECIALIZED POWER HYBRID DEVICES SHALL BE MAINTAINED AS PART OF THE TEST PROGRAM.

(4) TEST METHOD USED IS EQUIVALENT TO CONTRACTUAL REQUIREMENT AND CONFORMS MORE NEARLY TO STANDARD PRACTICES FOR POWER SEMI-CONDUCTOR DEVICES.

(5) ONE OF THE DEVICES SUCCESSFULLY PASSING THE IMMERSION TEST SHALL BE DISSECTED PER METHOD 2013 OF MIL-STD-883A.

TABLE II

SUMMARY - SEQUENCES 1 THRU 7

PHASE III TEST PROGRAM

SEQUENCE NO.	TEST	RESULTS	PLANNED CORRECTIVE ACTION
1	Physical Dimensions	Minor dimensional problems on all modules.	Improve molds.
2	Internal Visual	No defects noted.	
3	Electrical Tests	Experienced rejects for:	
		(a) Voltage Capability (6 SCR'S at -55^{0}C)	Need higher voltage SCR'S.
		(b) -55 Gate Trigger Current and Voltage (9 SCR'S)	Change 25^{0}C or -55^{0}C limits.
		(c) On-state Voltage (1 SCR)	
		(d) Turn-on Voltage (49 SCR'S)	Change limit.
4	External Visual	Minor defects due to poor molds Minor marking defects	Improve molds. Improve process control.
5	Insulation Resistance	2 Rejects	Improve process control.
6	Seal	0 Rejects	
7	Screening (Burn-In)		
	(a) Storage, Temp. Cycle	2 Rejects	Improve process control.
	(b) Blocking Life	6 Rejects (plus three fuse blowers)	Additional subscreet testing.
	(c) Seal	2 Lid Seal Leakers	Redesign Lid Seal.

TABLE III

ELECTRICAL TEST SUMMARY - SEQUENCE 3

PARAMETER	SPEC.	QTY REJECT SCR'S (72 SCR'S TOTAL)	RANGE OF MEASURED VALUES
Voltage Capability	1200V (repetitive) 1400V (non-repetitive)		
25^0C Off-state		2 < 1200V 34 < 1400V	
25^0C Reverse		1 < 1200V 7 < 1400V	
-55^0C Off-state		9 < 1200V 59 < 1400V	
-55^0C Reverse		9 < 1200V 9 < 1400V	
Off-State and Reverse Current 125^0C	15 mA max.	5	2 to 20.5 mA plus 3 O.R.
Gate Trigger Characteristics			
25^0C	150 mA/3 V max.	0	37 to 124 mA, 1.36 to 2.64V
-55^0C	250 mA/5 V max.	9	58 to 261 mA plus 1 O.R., 2.6 to 4.7 V plus 9 O.R.
$+125^0C$ (at 1200 volts peak)	0.25 V min.	0	0.45 to 0.85 volts
On-State Voltage 25^0C, 200 Amperes	2.7 V max.	1	1.67 to 5.84 volts
Turn-Off Time 125^0C	50 USEC max.	0	< 27 to 36 USEC
Turn-On Voltage 25^0C	8V Max. (9V Max.) (11V Max.)	49 (17) (1)	7.4 to 15.5 volts
Holding Current 25^0C	500 mA max.	0	34 to 115 mA

NOTE: O.R. = Over Range

TABLE IV SUMMARY - SEQUENCES 8 THRU 15

PHASE III TEST PROGRAM

SEQUENCE NO.	TEST	RESULTS	PLANNED CORRECTIVE ACTION
8	Reduced Barometric Press.	3 Rejects	Eliminate Seal Leaks.
9	Immersion	0 Rejects	
10	Salt Atmosphere	4 Peeling Plating	Improve Plating.
11	Thermal Resistance	6 SCR'S < 0.2 ^{0}C/Watt 6 SCR'S > 0.2 ^{0}C/Watt	Plate Copper Parts. Invert Lower Str. Cu. Test prior to Lid Seal.
12	Temperature Cycling	0 Rejects	
13	Thermal Shock	2 Reject Modules (3 Reject SCR'S)	Eliminate requirement.
14	Mechanical Shock	0 Rejects	
15	Vibration	1 Reject Module (2 Reject SCR'S)	Reduce Shear Stress on moly.

TABLE VA

PHASE III TEST RESULTS

DETAILED MODULE HISTORY GROUP 1 - SEQUENCE 1-7 INC.

SEQUENCE NO:	2	1	4	3	5	6		7	
MODULE/SCR NO.	INTERNAL VISUAL INSPECTION	PHYSICAL DIMENSIONS	EXTERNAL VISUAL INSPECTION	ELECTRICAL TESTS	INSULATION RESISTANCE	SEAL	BURN-IN ELECTRICAL AFTER STG & TEMP CYCLE	BURN-IN 96 HOUR BLOCKING	BURN-IN ELECTRICAL AFTER BLOCKING
3-1		1/	2/	3/					
3-2								Failed	Rej. V_R
4-1									
4-2							Gate Opened		
14-1									
14-2				$-55^{\circ}C$, Gate Rej.					
16-1									
16-2				$-55^{\circ}C$, Gate Rej.				Failed	Rej. V_R
18-1				$-55^{\circ}C$, V_D Rej.			V_D Rej.		Rej. V_D & V_R
18-2									
20-1				$-55^{\circ}C$, V_D Rej.			V_D Rej.	Failed	Rej. V_D
20-2									
50-1									
50-2									
52-1								Fuse Blower	
52-2								Fuse Blower	
60-1									
60-2								Fuse Blower	
62-1									
62-2									
65-1									
65-2									
68-1				$125^{\circ}C$, I_R Rej.				Failed	Rej. V_D & V_R
68-2									

NOTES: 1/ 2/ All Modules Deviate from Spec - Need Improved Molds and Fixtures.
3/ See Separate Chart for Sequence 3 Results
4/ Blank Spaces Indicate Satisfactory Performance.
5/ Rej. = Reject

TABLE VB

PHASE III TEST RESULTS

DETAILED MODULE HISTORY GROUP 2 - SEQUENCE 1-7 INC.

SEQUENCE NO:	2	1	4	3	5	6		7	
MODULE/SCR NO.	INTERNAL VISUAL INSPECTION	PHYSICAL DIMENSIONS	EXTERNAL VISUAL INSPECTION	ELECTRICAL TESTS	INSULATION RESISTANCE	SEAL	BURN-IN ELECTRICAL AFTER STG & TEMP CYCLE	BURN-IN 96 HOUR BLOCKING	BURN-IN ELECTRICAL AFTER BLOCKING
2-1		1/	2/	3/					
2-2									
5-1									
5-2									
7-1								Failed	Rej. V_D & V_R
7-2									
11-1									
11-2							Rej. V_D		V_D=1250V (improved)
13-1					Terminal				
13-2				V_{TM} Rej.	Short to Base			Fuse Blown	
15-1									
15-2									
17-1								Failed	Rej. V_R
17-2									
53-1				-55°C, V_R, Gate Rej.				Failed	I_D Increased
53-2									
55-1				-55°C, Gate Rej.					
55-2									
58-1				125°C, I_D Rej.			Rej. V_D & V_R	Failed	Rej. V_D & V_R
58-2				25°C&125°C, V_D& V_R Rej.			Rej. V_D & V_R	Failed	Rej. V_D & V_R
59-1				-55°C, V_D, V_R, Gate			Rej. V_D & V_R	Failed	Rej. V_D & V_R
59-2				25°C, V_D&I_R Rej.			Rej. V_D	Failed	Rej. V_D & V_R
66-1				-55°C, Gate Rej.					
66-2									

NOTES: 1/ 2/ All Modules Deviate from Spec - Need Improved Molds and Fixtures.
3/ See Separate Chart for Sequence 3 Results
4/ Blank Spaces Indicate Satisfactory Performance.
5/ Rej. = Reject

TABLE VC

PHASE III TEST RESULTS

DETAILED MODULE HISTORY GROUP 3 - SEQUENCE 1-7 INC.

SEQUENCE NO:	2	1	4	3	5	6		7	
MODULE/SCR NO.	INTERNAL VISUAL INSPECTION	PHYSICAL DIMENSIONS	EXTERNAL VISUAL INSPECTION	ELECTRICAL TESTS	INSULATION RESISTANCE	SEAL	BURN-IN ELECTRICAL AFTER STG & TEMP CYCLE	BURN-IN 96 HOUR BLOCKING	BURN-IN ELECTRICAL AFTER BLOCKING
1-1		1/	2/	$-55^{\circ}C, V_R$ 6/	Terminals				
1-2				$-55^{\circ}C$ V_R 6/	Short to Base		$125^{\circ}C, V_D$ Rej.	Failed	
6-1				3/					
6-2									
8-1									
8-2									
9-1									
9-2								Failed	Rej. V_D & V_R
21-1									
21-2									
51-1				$-55^{\circ}C$, Gate Rej.				Fuse Blower	
51-2									
54-1				$125^{\circ}C, I_D$ Rej.			Rej. V_D	Failed	Rej. V_D & V_R
54-2									
56-1				$-55^{\circ}C$, Gate Rej.					
56-2									
61-1								Failed	Rej. V_D & V_R
61-2									
63-1									
63-2									
64-1									
64-2									
67-1				$-55^{\circ}C$, Gate Rej.					
67-2				$25^{\circ}C, V_D$ & V_R 6/			Rej. V_D	Failed	Rej. V_D & V_R

NOTES: 1/ 2/ All Modules Deviate from Spec - Need Improved Molds and Fixtures.
3/ See Separate Chart for Sequence 3 Results.
4/ Blank Spaces Indicate Satisfactory Performance.
5/ Rej. = Reject
6/ Arcing Suspected.

TABLE VIA

PHASE III TEST RESULTS
SEQUENCE 3 ELECTRICAL TESTS - GROUP 1

Temp:	-55°C to +125°C	25°C, +125°C	125°C	125°C	25°C	-55°C	25°C	-55°C	125°C	25°C	125°C	25°C	25°C
Module/SCR No.	Voltage Capability	Off State And Reverse Current	dv/dt at 700 V	dv/dt at 1200 V	Gate Trigger Current	Gate Trigger Current	Gate Trigger Voltage	Gate Trigger Voltage	Gate Trigger	On-State Voltage	Turn-Off Time	Turn-On Voltage	Holding Current
	1200 Min. Volts	15 Max. mA	400 Min Volts/USEC	Volts/USEC	150 Max. mA	250 Max. mA	3 Max. Volts	5 Max. Volts	0.25 Min. Volts	2.7 Max. Volts	50 Max. USEC	8 Max. Volts	500 Max. mA
3-1				>200									
3-2												8.6	
4-1													
4-2													
14-1													
14-2								>5.0				8.9	
16-1												8.8	
16-2								>5.0				9.9	
18-1	$-55^{\circ}C, V_D = 218V$	Reject (after $-55^{\circ}C$)	Reject	Reject								8.2	
18-2				>200								9.3	
20-1	$-55^{\circ}C, V_D = 237V$	Reject (after $-55^{\circ}C$)	Reject	Reject								8.3	
20-2				>200									
50-1													
50-2												8.7	
52-1													
52-2													
60-1												9.5	
60-2												8.5	
62-1												8.6	
62-2												8.4	
65-1													
65-2												8.3	
68-1	$-55^{\circ}C, V_R = 671V$	Reject											
68-2												8.2	

NOTES: Blank Spaces Indicate Compliance with Test Limits

TABLE VIB

PHASE III TEST RESULTS
SEQUENCE 3 ELECTRICAL TESTS - GROUP 2

Temp:	$-55^{o}C$ to $+125^{o}C$	$25^{o}C$, $+125^{o}C$	$125^{o}C$	$125^{o}C$	$25^{o}C$	$-55^{o}C$	$25^{o}C$	$-55^{o}C$	$125^{o}C$	$25^{o}C$	$125^{o}C$	$25^{o}C$	$25^{o}C$
Module/SCR No.	Voltage Capability	Off State And Reverse Current	dv/dt at 700 V	dv/dt at 1200 V	Gate Trigger Current	Gate Trigger Current	Gate Trigger Voltage	Gate Trigger Voltage	Gate Trigger	On-State Voltage	Turn-Off Time	Turn-On Voltage	Holding Current
	1200 Min. Volts	15 Max. mA	400 Min Volts/USEC	Volts/USEC	150 Max. mA	250 Max. mA	3 Max. Volts	5 Max. Volts	0.25 Min. Volts	2.7 Max. Volts	50 Max. USEC	8 Max. Volts	500 Max. mA
2-1				>200								8.8	
2-2													
5-1												8.3	
5-2												8.5	
7-1												8.4	
7-2													
11-1												8.5	
11-2												8.3	
13-1												8.5	
13-2										5.84		15.5	
15-1												8.9	
15-2												9.5	
17-1												9.3	
17-2												8.5	
53-1	$-55^{o}C, V_R=0$ 1/							>5.0				9.7	
53-2													
55-1						261		>5.0				10.1	
55-2													
58-1	$-55^{o}C, V_D$ & $V_R=320$	$125^{o}C, I_D=20.5$	Reject	Reject									
58-2	$-55^{o}C, V_D=800$	$25^{o}C, I_D$ O.R. 2/	Reject	Reject								8.8	
59-1	$-55^{o}C, V_D=0, V_R=800$		Reject	Reject		257		>5.0				9.3	
59-2	$25^{o}C, V_D=950$	$25^{o}C, I_R=$O.R. 2/	Reject	Reject								9.0	
66-1				>200				>5.0				8.3	
66-2				>200									

NOTES: 1/ Arcing Suspected
2/ O.R. = Over Range
3/ Blank Spaces Indicate Compliance with Test Limits

TABLE VIC

PHASE III TEST RESULTS
SEQUENCE 3 ELECTRICAL TESTS - GROUP 3

Temp:	-55°C to +125°C	25°C, +125°C	125°C	125°C	25°C	-55°C	25°C	-55°C	125°C	25°C	125°C	25°C	25°C
Module/SCR No.	Voltage Capability	Off State And Reverse Current	dv/dt at 700 V	dv/dt at 1200 V	Gate Trigger Current	Gate Trigger Current	Gate Trigger Voltage	Gate Trigger Voltage	Gate Trigger	On-State Voltage	Turn-Off Time	Turn-On Voltage	Holding Current
	1200 Min. Volts	15 Max. mA	400 Min Volts/USEC	Volts/USEC	150 Max. mA	250 Max. mA	3 Max. Volts	5 Max. Volts	0.25 Min. Volts	2.7 Max. Volts	50 Max. USEC	8 Max. Volts	500 Max. mA
1-1	$-55^{o}C, V_R=1128$ 1/			>200								8.7	
1-2	$-55^{o}C, V_R=639$ 1/	O.R. 2/	Reject	Reject								8.8	
6-1				>200								8.4	
6-2												8.8	
8-1												8.5	
8-2												9.5	
9-1												8.7	
9-2													
21-1												9.2	
21-2												9.2	
51-1						261		>5.0				8.7	
51-2												9.1	
54-1	$-55^{o}C, V_D \& V_R<200$	$125^{o}C, I_D=20$	Reject	Reject								8.3	
54-2				>200								8.9	
56-1								>5.0					
56-2													
61-1												8.9	
61-2												9.8	
63-1													
63-2													
64-1													
64-2													
67-1						O.R.		>5.0				9.3	
67-2	$25^{o}C, V_D=781, V_R=0$ 1/		Reject	Reject								9.3	

NOTES: 1/ Arcing Suspected
2/ O.R. = Over Range
3/ Blank Spaces Indicate Compliance with Test Limits

TABLE VIIA

PHASE III TEST RESULTS

DETAILED MODULE HISTORY GROUP 1 - SEQUENCES 8 TO 15 INC.

SEQUENCE NO:	8	8A	11	13A	14	15A	15B
MODULE/SCR NO.	REDUCED BAR. PRESSURE	SEAL	THERMAL RESISTANCE	ELECTRICAL TEST AT 25°C	MECHANICAL SHOCK	ELECTRICAL TEST AT 25°C	SEAL
3-1	REJ., 600V		1/	2/		2/	
3-2							
4-1		LID					LID
4-2		LEAK					LEAK
14-1							
14-2							
16-1		LID					LID
16-2		LEAK					LEAK
18-1							
18-2							
20-1							
20-2							
50-1							
50-2	REJ., 10[illegible]0V						
52-1							
52-2							
60-1							
60-2							
62-1	REJ., 1000V						
62-2	REJ., 700V						
68-1							
68-2							

NOTES:
1/ ERRONEOUS RESULTS OBTAINED USING ELECTRICAL TEST METHOD.
2/ ELECTRICAL TESTS FOLLOWING SEQUENCES 8, 11, AND 14 SHOWED NO SIGNIFICANT CHANGES FROM TESTS FOLLOWING SEQUENCE 7.
3/ REJ. = REJECT
4/ BLANK SPACES INDICATE NO CHANGES OR DEFECTS OBSERVED.

AD-A119 424 GENERAL ELECTRIC CO BINGHAMTON NY ARMAMENT AND ELECT--ETC F/G 20/12
LIQUID COOLED VARIABLE SPEED CONSTANT FREQUENCY (VSCF) CONVERTE--ETC(U)
JUN 82 J W BUTLER F33615-78-C-2029
UNCLASSIFIED AES-13589 AFWAL-TR-82-2048 NL

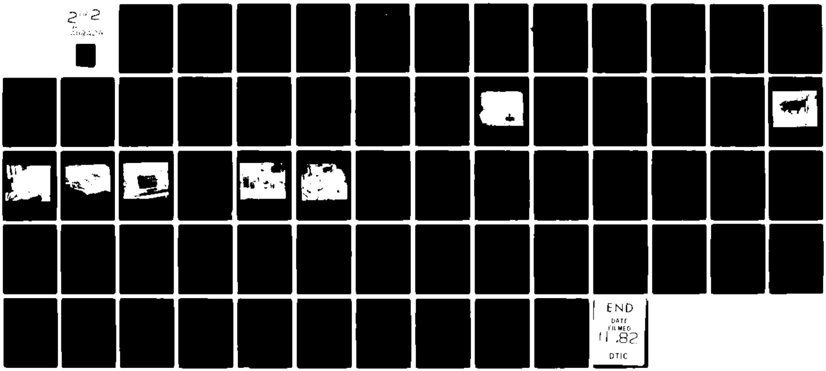


TABLE VIIB

PHASE III TEST RESULTS

DETAILED MODULE HISTORY GROUP 2 - SEQUENCES 8 TO 15 INC.

SEQUENCE NO:	9	12	13A	13B1	15	15A	15B
MODULE/SCR NO.	IMMERSION	TEMP. CYCLING	ELECTRICAL TEST AT 25°C	SEAL	VIBRATION	ELECTRICAL TEST AT 25°C	SEAL
2-1			1/			Rej. V_D & V_R	
2-2						Rej. V_D & V_R	
5-1						1/	
5-2							
7-1							
7-2						3/	
11-1						3/	
11-2							
13-1						3/	
13-2						3/	
15-1							
15-2							
17-1							LID
17-2							LEAK
53-1							
53-2							
55-1						3/	
55-2						3/	
58-1							
58-2							
59-1							
59-2							
66-1							LID
66-2							LEAK

NOTES: 1/ Electrical Tests following Sequences 9, 12, and 15 showed no significant changes from tests following Sequence 7 except as noted.

2/ Rej. = Reject

3/ These Modules exhibited increases in off-state and/or reverse current at 1200 volts.

4/ Blank spaces indicate no changes or defects observed.

TABLE VIIC

PHASE III TEST RESULTS

DETAILED MODULE HISTORY GROUP 3 - SEQUENCES 8 TO 13 INC.

SEQUENCE NO.:	10	13	13A	13B	
MODULE/SCR NO.	SALT ATMOSPHERE	THERMAL SHOCK	ELECTRICAL TEST AT 25°C	SEAL	ELECTRICAL TEST AT 25°C (FOLLOWING 24 HOUR, 125°C BAKE)
1-1			REJ., V_D&V_R	3/	RECOVERED
1-2			REJ., V_D&V_R		RECOVERED
6-1			REJ., V_D&V_R		
6-2			REJ., V_D&V_R		
8-1			REJ., V_D&V_R		RECOVERED
8-2			REJ., V_D&V_R		RECOVERED
9-1	MINOR ALUMINUM		REJ., V_D&V_R		V_D&V_R RECOVERED BUT I_R INCREASED
9-2	PITTING				
21-1	PLATING				
21-2	PEELING		REJ., V_R		RECOVERED
51-1			I_D&I_R INCREASED		RECOVERED
51-2			REJ., I_D&I_R		RECOVERED
54-1	PLATING				
54-2	PEELING				
56-1	MINOR ALUMINUM				
56-2	PITTING		I_D INCREASED		RECOVERED
61-1	MINOR ALUMINUM				
61-2	PITTING				
63-1	MINOR ALUMINUM				
63-2	PITTING				
64-1	PLATING				
64-2	PEELING				
67-1	PLATING				
67-2	PEELING				

NOTES: 1/ BLANK SPACES INDICATE NO CHANGES OR DEFECTS OBSERVED.
2/ REJ. = REJECT
3/ NO SEAL LEAKS DETECTED BUT SEVERAL UNDETECTED LEAKERS SUSPECTED.

TABLE VIIIA

PHASE III TEST PROGRAM
MODULE FAILURE ANALYSIS

MODULE/SCR NO.	TEST GROUP	REASON FOR ANALYSIS	THERMAL RESISTANCE INITIAL (ELECTRICALLY) $^{0}C/WATT$	THERMAL RESISTANCE AFTER LID REMOVAL (TEMP. PROBE METH.) $^{0}C/WATT$	FINDINGS	CONCLUSION/CORRECTIVE ACTION
3-1	1	600V on reduced barometric pressure.	1.65	1.36	Lid solder ran close to E3 feedthru. RTV pulled away from case.	Undetected seal leaker. Assemble with foil side of structured copper toward BEO.
3-2		High thermal resistance Reverse Voltage downgrade. After blocking life screen test. High thermal resistance.	1.37	1.30	Both 3-1 and 3-2 had poor foil to structured Cu bonds. Also many solder void areas. Also both have cracked moly (in plane of disc).	Improve soldering by plating copper parts. Reduce shear stress on moly by redesigning copper straps. Redesign lid to improve seal.
4-2		Gate opened after temp. cycle screen. Module was case seal leaker after screen tests.			Module inadvertently filled with RTV which forced Lid up and pulled off gate lead.	Improve process control.
16-2		Reverse voltage downgrade after blocking life screen test. Case seal leaker after screen tests.	0.59	0.55	Tracks visible on silicon bevel. Poor foil to structured Cu bond. Moly disc cracked (in plane of disc). Lid solder seal cracked.	Same as for Module No. 3 above.

(continued)

PHASE III TEST PROGRAM - MODULE FAILURE ANALYSIS (continued)

TABLE VIIIB

MODULE/SCR NO.	TEST GROUP	REASON FOR ANLAYSIS	THERMAL RESISTANCE INITIAL (ELECTRICALLY) $^{0}C/WATT$	THERMAL RESISTANCE AFTER LID REMOVAL (TEMP. PROBE METH.) $^{0}C/WATT$	FINDINGS	CONCLUSION/CORRECTIVE ACTION
50-2		1000V breakdown on reduced barometric pressure.	0.69	-	Nothing obvious.	Conclude module was an undetected seal leaker.
62-1		Same as 50-2.	0.43	0.12	Nothing obvious.	Same as 50-2.
62-2		" " "	0.48	0.15	Nothing obvious.	" " "
2-1 2-2	2	Voltage ejects after vibration.	-	-	No silicon damage visible but both have cracks in moly (in plane of disc).	Redesign internal copper straps to reduce shear stress on moly.
7-1		Voltage reject after blocking life screen test.	-	0.15	Silicon cracked radially across junction.	Reason undetermined. Reduce stress on silicon
7-2		Increase in reverse current after vibration.	-	0.30	Small crack in moly (in plane of disc).	
13		Insulation Resistance reject			Top copper touching case. Lid solder may have ran down. No evidence of corrosion from immersion test.	Redesign copper straps. Improve process control.
17-1		Voltage reject after blocking voltage screen test. Leaker after vibration.	-	-	Silicon cracked radially. Lid solder cracked between small solder voids.	Reduce stress on silicon. Redesign lid to improve seal.

(continued)

PHASE III TEST PROGRAM - MODULE FAILURE ANALYSIS (continued)

TABLE VIIIC

MODULE/SCR NO.	TEST GROUP	REASON FOR ANALYSIS	THERMAL RESISTANCE INITIAL (ELECTRICALLY) ^{o}C/WATT	THERMAL RESISTANCE AFTER LID REMOVAL (TEMP. PROBE METH.) ^{o}C/WATT	FINDINGS	CONCLUSION/CORRECTIVE ACTION
59-1		Voltage reject at -55^{o}C.	-	0.15	Small shallow crack in silicon at outside edge of bevel.	Reduce stress on silicon.
59-2		" " " "	-	0.20	No flaw observed.	
6-1	3	Voltage reject after thermal shock.	-	0.25	Not analyzed.	
6-2		Same as 6-1	-	1.25	Damage on silicon bevel. Silicon chipped under top structured copper at outer edge. Copper foil broken loose from lower structured copper.	Redesign copper straps for reduced stress on silicon. Mount lower structured copper with foil side toward BEO. Plate copper parts for improved soldering.

TABLE IX

CORRECTIVE ACTION FOR PHASE IV

1. IMPROVE CONTROL ON STRUCTURED COPPER TO FOIL BONDING.
2. INVERT LOWER STRUCTURED COPPER - (FOIL TOWARD BEO).
3. PLATE COPPER PARTS FOR IMPROVED BONDING.
4. PERFORM 100% THERMAL RESISTANCE TEST PRIOR TO LID SEAL.
5. PERFORM BLOCKING LIFE TEST ON SUBASSEMBLIES.
6. REDESIGN LID SEAL.
7. REDESIGN COPPER STRAPS.
8. SWITCH TO SILVER GATE LEAD.
9. REDESIGN FIXTURES AND MOLDS.
10. INVESTIGATE IMPROVED SEAL LEAK TEST PROCEDURE.
11. IMPROVE CONTROL OVER ALUMINUM SURFACE PLATING.

5.0 APPENDIX

The following terms and symbols, used in this report are further defined in MIL-S-19500:

Terms and Symbols

SCR	-	Silicon controlled rectifier
V_R	-	SCR reverse voltage
V_D	-	SCR off-state voltage
V_{TM}	-	SCR on-state voltage
I_R	-	SCR reverse current
I_D	-	SCR off-state current
dv/dt	-	SCR critical rate of rise of off-state voltage

SSPC QUALITY CONTROL INSTRUCTION

Date October 10, 1979	Title Pre-Seal Visual Insp.		Number GCMQ2000.8.0
Rev.No. 0	Project Hermetic VSCF		Page 1 of 4
Responsible Unit Assemblies Operation			Plant

1. PURPOSE

1.1 The purpose of this instruction is to meet the requirements of specification control drawing 28348357 paragraph 4.5 internal visual inspection for the Hermetic VSCF Module.

2. EQUIPMENT

2.1 Stereo microscope 10-60X with suitable illumination.

2.2 Photo optics capable of recording the internal cavity of the VSCF package in one exposure.

3. PROCEDURE

3.1 Perform the visual inspection as appropriately excerpted form MIL-STD-883 Method 2017.1, 31 August 1977 per the following:

3.1.1 Component assembly to substrate, "magnification 10-60X." No device shall be acceptable that exhibits:

3.1.1.1 Solder or alloy component mounting (active and passive):

a. Solder or allow not visible around at least 50 percent of the component perimeter or continuous on two sides of the component whichever is less.
   NOTE: End terminated components that have a fillet length less than 50 percent of the visible bonding perimeter on each end are not acceptable.
b. Component attach area less than 50 percent where the solder or alloy may be observed (i.e., glass substrate viewed from the bottom, transparent die).
   NOTE: This criterion may be employed in lieu of 3.1.1.1a.
c. Solder or alloy buildup that extends onto the top surface of the component.
   NOTE: End terminated components are excluded from this criteria.
d. Presence of any residual flux.
   NOTE: Use 10 to 15X magnification for passive components.
e. Foreign material in melt that does not exhibit a fillet.
f. Flaking of the solder or alloy material.
g. Balling of the solder or alloy material that does not exhibit a fillet (see figure 1)
h. Solder or alloy material run out towards any isolated component or deposited element that leaves less than 0.3 mil separation.
   NOTE: Unused components are unused deposited elements are excluded from this criteria.
i. Solder or alloy material on wire on beam lead bonding pad that leaves an area less than twice the maximum allowable bond size free from such material

Reference Dwg.	Approvals	
28348357	[signature] 11/12/79	SSPC-177

SSPC QUALITY CONTROL INSTRUCTION

Date October 10, 1979	Title Pre-Seal Visual Insp.	Number GCMQ2000.8.0
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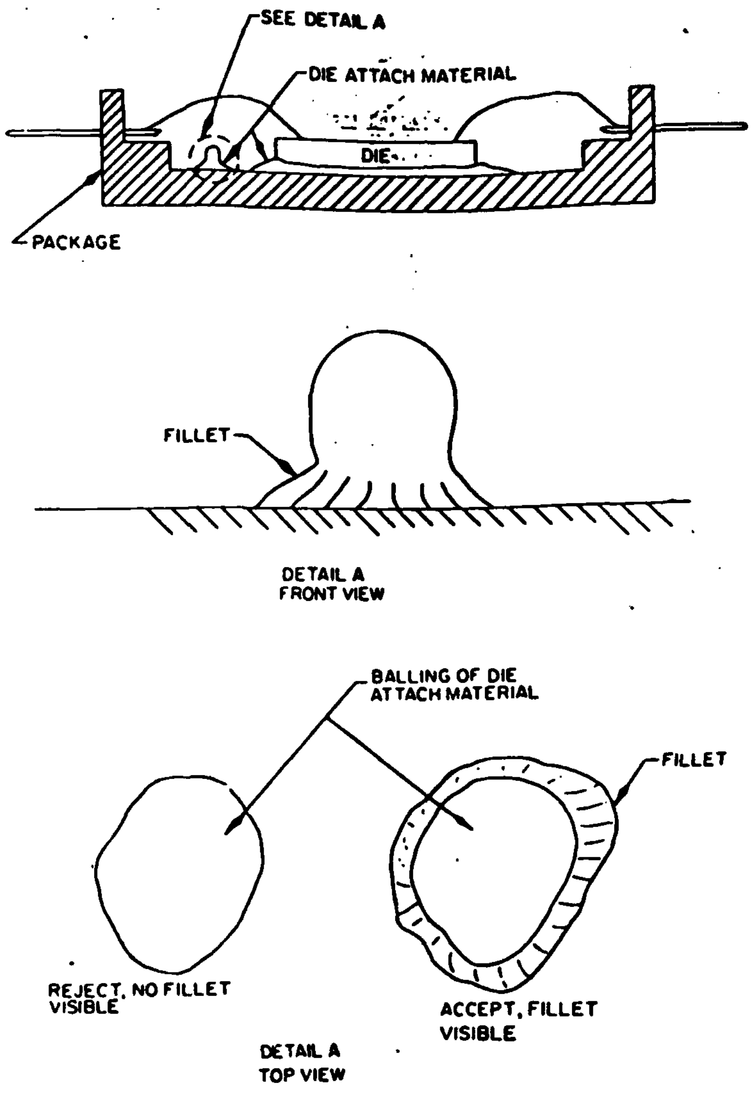

FIG. 1

Reference Dwg. 28348357

Approvals *Parikh 10/12/79*

SSPC-177

SSPC QUALITY CONTROL INSTRUCTION

Date October 10, 1979 Title Pre-Seal Visual Insp. Number GCMQ2000.8.0

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Responsible Unit Assemblies Operation Plant

3.1.1.2 Component orientation. Component not located or oriented in accordance with the applicable assembly drawing of the device.

3.1.2 Substrate mounting to package, "magnification 10 to 60X." No device shall be acceptable that exhibits:

3.1.3.1 Solder or alloy mounting:

a. Solder or alloy material not visible around at least 50 percent of the substrate perimeter or continuous on two sides of the substrate, whichever is less.
b. Solder or alloy material buildup that touches the top surface of the substrate and reduces the separation between the mounting material and operating metallization to less than 0.3 mil.
c. Presence of any residual flux.
   NOTE: Use 10 to 15X magnification for passive components.
d. Foreign material in melt that does not exhibit a fillet.
e. Flaking of the solder or alloy material.
f. Balling of the solder or alloy material that does not exhibit a fillet (see figure 1)
g. Less than 50 percent alloy or solder fillet around the circumference of the mounting posts when designed for substrate to post attachment.
h. Less tahn 25 percent fillet around the mounting post when substrate is mechanically attached by back side soldering or alloying.
i. Solder or alloy buildup that comes closer than 0.3 mil to package leads.

3.1.2.2 Substrate orientation. Substrate not located and oriented in accordance with the applicable assembly drawing of the device.

3.1.3 Package conditions, "magnification 10 to 60X." No device will be acceptable that exhibits:

3.1.3.1 Foreign material:

a. Unattached foreign material on the surface of the die, substrate, or within that package.
b. Unattached foreign material on the surface of the lid or cap.
   NOTE: Criteria can be satisfied by a nominal gas blow (approximately 20 psig) or a suitable cleaning process, providing the lids or caps are subsequently held in a controlled environment until capping.
c. Attached conductive foreign material that bridges metallization paths, two package leads, lead to package metallization, functional circuit elements, junctions, or any combination thereof.
d. Structured copper filaments attached at only one end.

Reference Dwg. 28348357

Approvals ... 11/12/79

SSPC-177

SSPC QUALITY CONTROL INSTRUCTION

Date October 10, 1979 Title Pre-Seal Visual Insp. Number GCM02000.8.0

Rev.No. 0 Project Hermetic VSCF Page 4 of 4

Responsible Unit Assemblies Operation Plant

4. DOCUMENTATION:

4.1 Fill out attached check list for each module after completion of visual inspection.

4.2 Make a 3½" x 4½" color photograph of each module, identify the serial number of the module on the photograph and attach to the check list for that module.

4.3 Maintain suitable file for storage of this documentation.

4.4 After sealing perform hermeticity check per MIL-STD-883 method 1014.2 test condition A_2 and record on check list. Maximum leak rate 5×10^{-6} atm. CC/SEC HE, soak time 1.0 HR. at 2.0 atmospheres.

5. HERMETIC VSCF VISUAL INSPECTION CHECK LIST

ITEM		ACCEPT	REJECT	OPER.	DATE
3.1.1.1	Solder or alloy component mounting	____	____	____	____
3.1.1.2	Component orientation	____	____	____	____
3.1.2.1	Solder mounting substrate to package	____	____	____	____
3.1.2.2	Substrate orientation	____	____	____	____
3.1.3.1	Package conditions foreign material	____	____	____	____
4.2	Photograph Taken	____	____	____	____
4.4	Leak Rate	____	____	____	____

MODULE SERIAL NO. ____________

Reference Dwg.
28348357

Approvals
P.W. Clark 12/12/79

SSPC-177

SSPC QUALITY CONTROL INSTRUCTION

Date Oct. 15, 1979	Title External Visual	Number GCMQ2000.9.0
Rev.No. 0	Project Hermetic VSCF	Page 1 of 2
Responsible Unit Assemblies Operation		Plant

1. Purpose

The Purpose of this instruction is to meet the requirements of specification control drawing 28348357 Table V Group B Sub Group I External Visual inspection.

2. Apparatus

Apparatus used in this test shall be capable of demonstrating device conformance to the applicable requirements, which may include optical equipment capable of magnification between 3X and 10X and a relatively large and accessible field of view such as an illuminated ring magnifier.

3. Procedure

Perform the visual inspection as excerpted from MIL-STD-883 method 2009.1 15 November 1974 and as added to per the following:

3.1. The device shall be examined under a magnification of between 3X and 10X (unless otherwise specified) with a field of view sufficiently large to contain the entire device in accordance with the requirements of the applicable procurement specification and the criteria listed in 3.1.1, where adherence of foreign material is in question, devices may be subjected to a clean filtered air stream (suction or expulsion) of 88 feet per second maximum, and reinspected.

3.1.1 Failure criteria. Devices shall be considered to fail if they exhibit the following:

(a) Device design, lead identification, markings (content, placement, and legibility), materials, construction, and workmanship are not in accordance with the applicable specification.

(b) Defects or damage resulting from manufacturing, handling or testing.

(c) Visible evidence of corrosion, contamination or breakage (grossly bent or broken leads, cracked seals (except for glass meniscus)), defective(peeling, flaking, or damaged plating. (Discoloration of the finish shall not be cause for failure unless there is evidence of flaking, pitting, or corrosion.)

(d) Leads which are not intact and aligned in their normal location, free of sharp or unspecified lead bends, and (for ribbon leads) free of twist outside the normal lead plane.

Reference Dwg. 28348357

Approvals DWD 10/12/79

SSPC-177

SSPC QUALITY CONTROL INSTRUCTION

Date Oct. 15, 1979	Title External Visual	Number GCMO2000.9.0	
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(e) Leads which are not free of foreign material such as paint or other adherent deposits, or dust.

(f) Other defects or features which will interfere with the normal application of the device.

(g) Evidence of any nonconformance with the detail drawing or applicable procurement document, absence of any required feature, or evidence of damage, corrosion, or contamination which will interfere with the normal application of the device.

(h) Base not flat with projections or foreign material.

Reference Dwg. 28348357	Approvals PMO 11/12/79	SSPC-177

SSPC QUALITY CONTROL INSTRUCTION

Date Oct. 15, 1979	Title External Visual	Number GCMQ2000.9.0
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4. Documentation

4.1 Record below certification that the VSCF module has been submitted to External Visual Inspection. Comments may be written on back of sheet.

4.2 Maintain suitable file for storage of this documentation.

5. Hermetic VSCB External Visual Certification.

Module Ser. #	Accept	Reject	Oper	Date

Reference Dwg. 28348357	Approvals [illegible] 6/11/79	SSPC-177

APPENDIX E

VSCF SYSTEM PERFORMANCE TEST REPORT

GENERAL REPORT SUMMARY SHEET

1. COMPONENT/PART NAME PER GENERIC CODE Hybrid Power Module	2. PROGRAM OR WEAPON SYS Electrical Systems	3.	DAY	MO	YR
	5. ORIGINATOR'S REPORT NO AES 13,591	TEST COMPL	3	12	81
4. ORIGINATOR'S REPORT TITLE VSCF Converter Device Development System Test Performance		REPT COMPL	12	1	82
	6. TEST TYPE, ETC. VSCF System				

7. THIS TEST (SUPERSEDES) (SUPPLEMENTS) REPORT NO: N/A

8. OUTLINE, TABLE OF CONTENTS, SUMMARY, OR EQUIVALENT DESCRIPTION:

The power module is a dual SCR device featuring two 18 mm silicon SCR pellets mounted in a hermetically sealed aluminium housing and bonded to an electrically isolated mounting base. Low thermal resistance and mechanical stability are achieved by the use of structured and direct-bond copper. Refer to Photo #1.

The testing of the power hybrids (SCR Modules) in a simulated PMG VSCF system was completed with no evidence of deterioration or malfunction of the hybrids. This testing included application of overloads and short circuits as well as a 50 hour endurance test.

11. REPT. NO. TBD

9. SIGNED	10. CONTRACTOR	SUBCONTRACTOR
	General Electric Company	

NOTICES PAGE

Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

Index of Revisions

Document Page	Revision	1	2

REASON FOR TEST

Contractual requirement for Phase V per Performance Test Procedures, CDRL Item 0002, Sequence 10 (See Appendix F).

This test is to evaluate performance of quantity 18 SCR Power Modules in a six phase permanent magnet generator VSCF cycloconverter electrical generating system.

DESCRIPTION OF TEST SAMPLES

The power module is a dual SCR device featuring two 18 mm silicon SCR pellets mounted in a hermetically sealed aluminum housing and bonded to an electrically isolated mounting base. Low thermal resistance and mechanical stability are achieved by the use of structured and direct-bond copper. Refer to Photo #1.

The detailed requirements of the SCR power modules are described on Specification Control Drawing 283A8357.

Their construction and fabrication are explained in an IEEE technical paper (80CH1554-5 NAECON) presented at the 1980 NAECON meeting in Dayton, Ohio, May 20 and 22, "Dual SCR Power Module."

100280-20CN

Photo #1. Power Module

DISPOSITION OF TEST SAMPLES

All SCR Power Modules fabricated on this contract will be delivered to AFWAL/POOS-2 as part of the project.

The breadboarded VSCF system including the converter, power hybrid section, control panel and associated cabling and oil lines will be consigned to AFWAL.

The 150 KVA VSCF oil cart will be returned to AFWAL for use as the power hybrid section heat exchanger and pump.

CONCLUSION

The testing of the power hybrids (SCR Modules) in a simulated PMG VSCF system was completed with no evidence of deterioration or malfunction of the hybrids. Although the final system test procedure was somewhat reduced in scope (i.e., endurance test reduced to 50 hour duration and overload short circuit and temperature cycling portions of the endurance test eliminated), the ultimate intent of the contract has been successively achieved.

The maximum measured module base temperature was 97.6°C compared to a design maximum of 100°C and the measured maximum power loww dissipated by the Hybrid Power Section was 2,646 watts compared to a calculated value of 2,700 watts.

REFERENCES

1. Contract - VSCF Converter Device Development #F33615-78-C-2029.

2. Semiconductor Device, Dual Thyrister 89954 - 283A8357.

3. Technical Paper (SOCH1554-5 NAECON) "Dual SCR Power Module" presented in May 20-22, 1980 at NAECON in Dayton, Ohio.

DESCRIPTION OF TEST APPARATUS

The VSCF test system consists of four assemblies as follows:

	Name	Part Number
A.	Generator Unit (GU)	2CM431A1X
B.	Converter Unit (CU) (Less Power Hybrid)	936E160G1
C.	Current Transformer Assembly (CTA)	3S2060DT105
D.	Power Hybrid Section (PHS)	936E174G1

1. The "GU" is an existing 2CM431 modified to electrically simulate a permanent magnet machine.

2. The "CU" is a breadboard VSCF system less the power hybrid section, capable of supplying 60 KVA, 115/200 VAC three phase 400 Hz power when operated with the "GU".

3. The "CTA" contains three single phase current transformers which are used in conjunction with the "CU" to provide feeder fault protection.

4. The "PHS" contains the Power Hybrid Modules (PHM), driver circuits and heat exchanger.

Refer to Photo numbers 2, 3, 4 and 5.

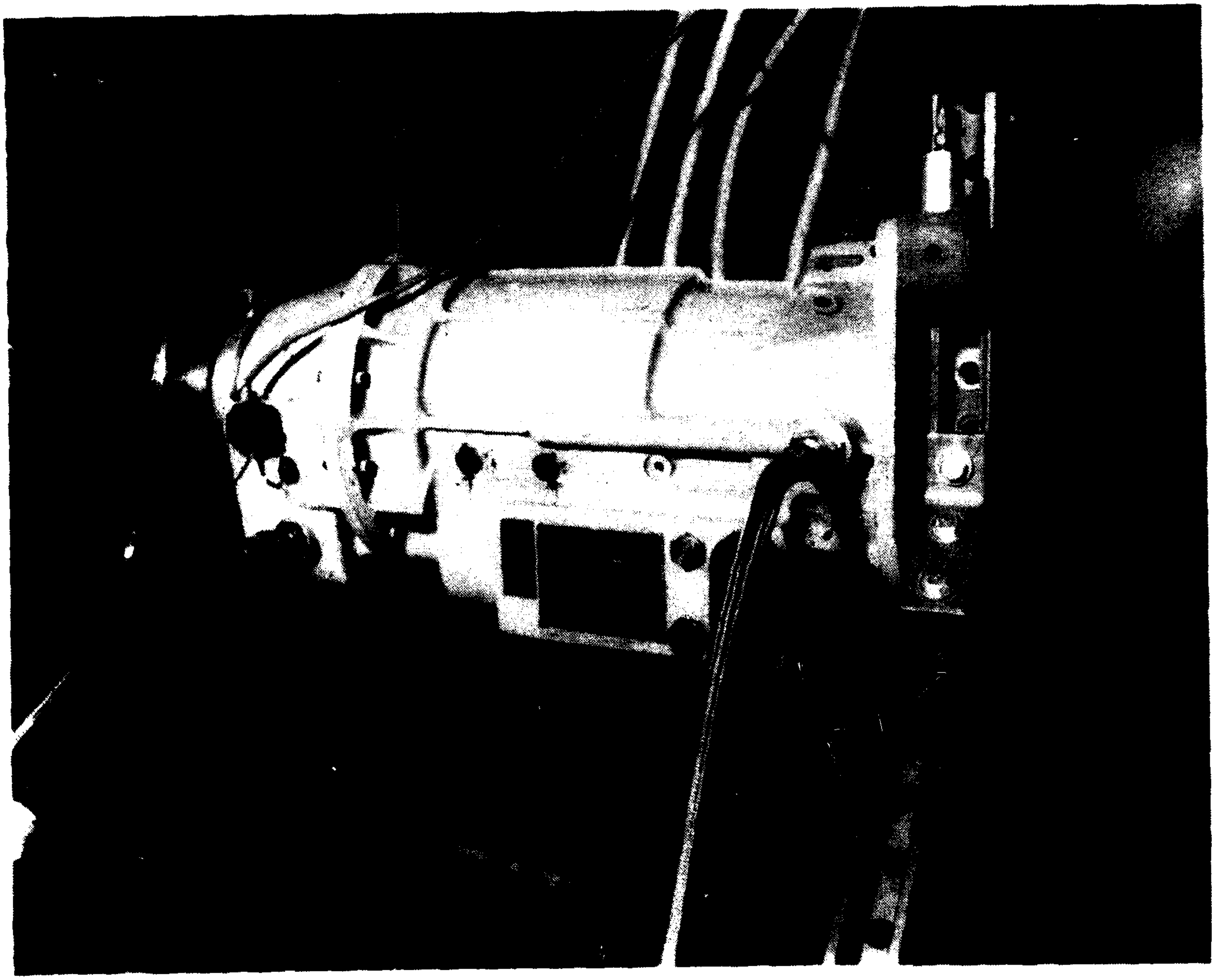

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Photo #2. Generator

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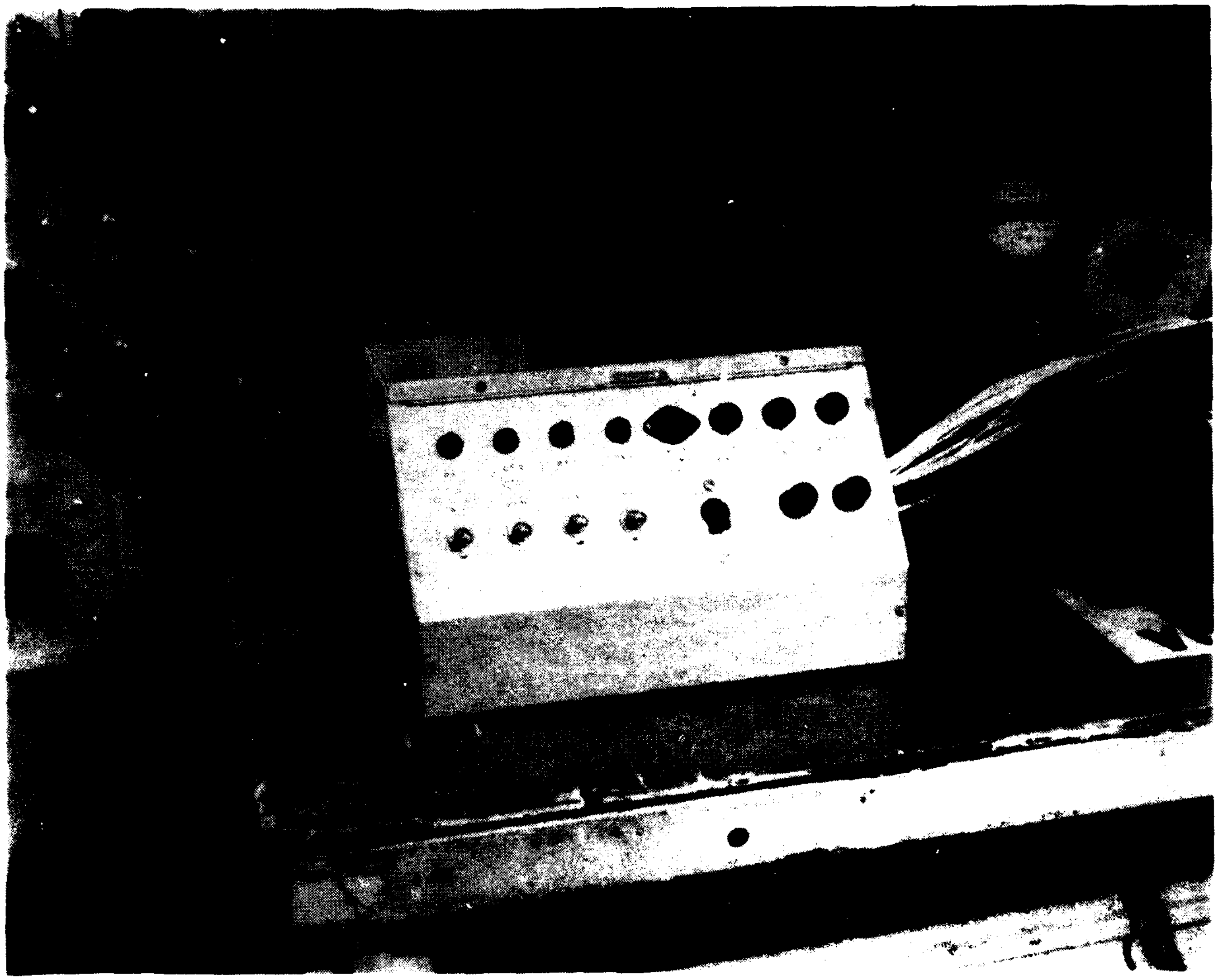
Photo #3. Converter Section

29982

Photo #4. Power Hybrid Section



29984

Photo #5. System Control Panel

TEST PROCEDURE

(Refer to Photo #6 and #7 for set-up)

These are defined in detail in Appendix F with the following exception/deletions.

The power hybrid section oil flow was maintained approximately at 6.4 gal/min. The generator rotor was leak tested during manufacture at 100 psi; but the assembled machine is an open pressure system; and therefore, cannot be proof pressure tested. Generator torque was not monitored, but the relative generator cooling oil flow rate was recorded along with the generator inlet and outlet oil pressure.

The power hybrid cooling plate was proof pressure tested at 250 psi for 5 minutes by the supplier of the heat exchanger.

Following completion of the overload tests at base speed, it was decided to finish an endurance test prior to the balance of the overload and short circuit tests.

The endurance test, paragraph 5.2.10, was reduced to 50 hours duration and the overload, short circuit and temperature cycling portions of the endurance test eliminated.

Following the 50 hour endurance test, all overload and short circuit tests were completed as required.

31280

Figure #6. General Test Set-Up

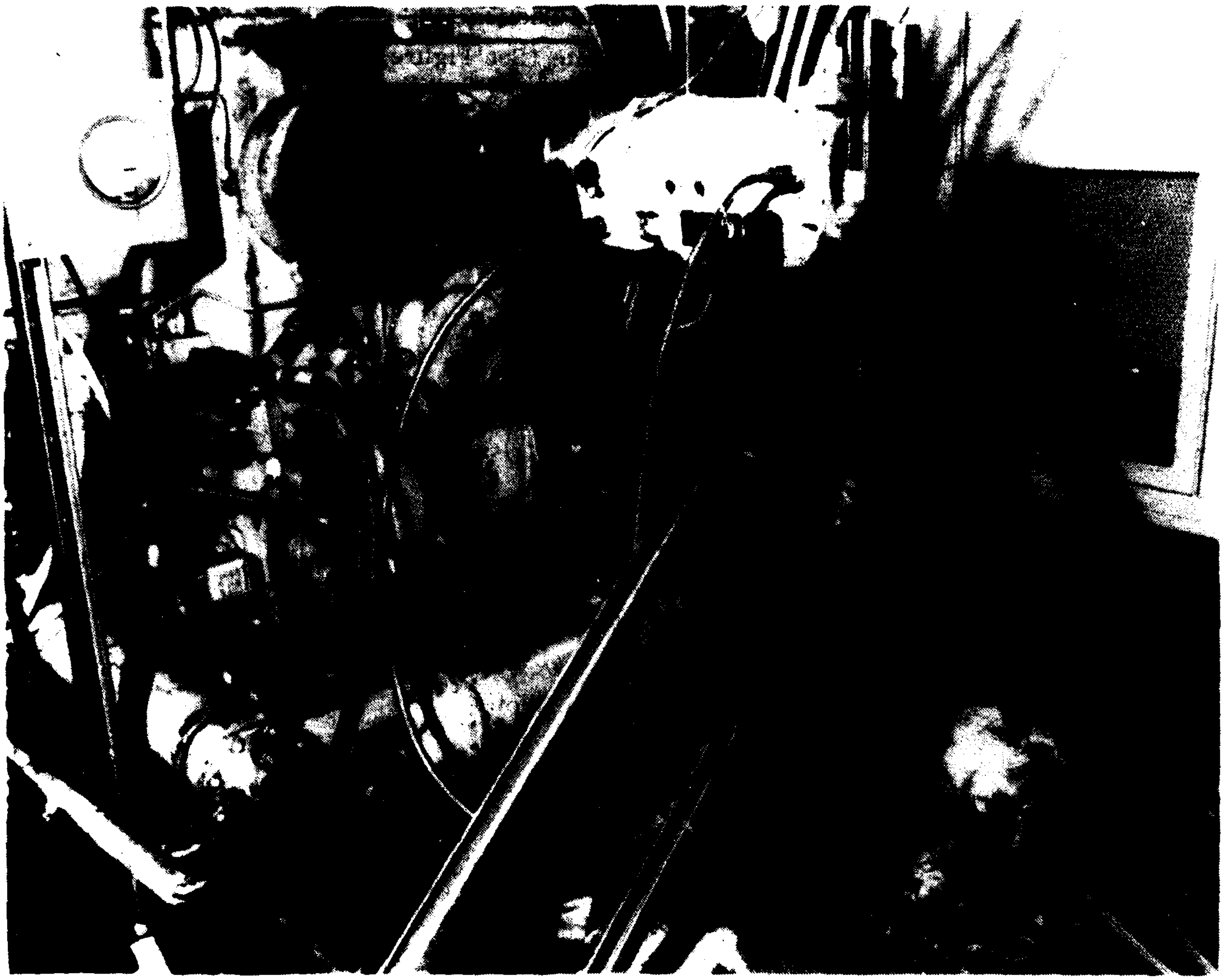


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Figure #7. Generator Installation on Drivestand

THERMOCOUPLE LOCATIONS

Number	Description
	Power Hybrid Section
1 - 12	SCR Cold Plate (See Figure 1)
	Converter
13	VR-2
14	IPT Coil
15	VR-1
16	Q4
17	Power Supply Chassis
18	Chassis near VR-3
19	Lower IPT Heat Sink
20	IPT Core
21	Top IPT Heat Sink
22	IPT Inlet Air
23	Oil In (PHS)
24	Oil Out (PHS)
25	Room Air
26	Generator Oil Inlet

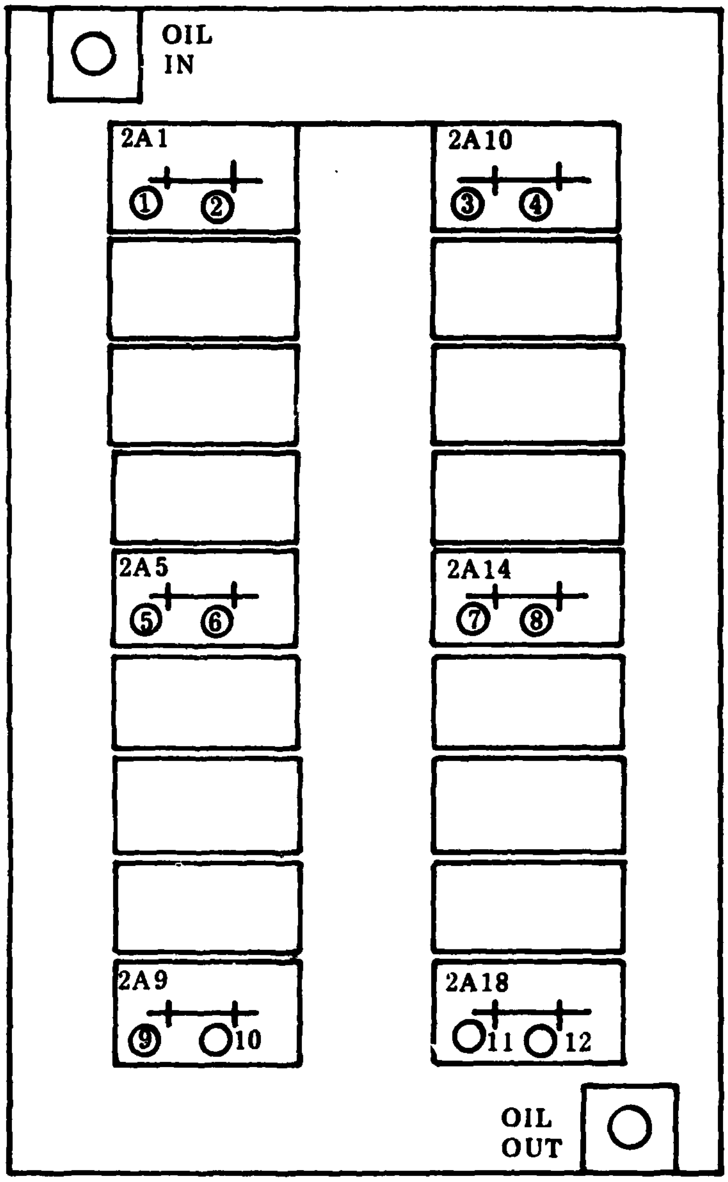


Figure 1. SCR Cold Plate

TEST DATA SUMMARY

A permanent test file has been established where all test and data sheets will be stored for future reference if needed.

Generator Weight = 118.5 lbs. (Test paragraph number - 5.2.1)	22 January 1981
Total Converter Weight = 105 lbs. (Test paragraph number - 5.2.2)	22 January 1981
Successfully completed generator dielectric strength test	15 January 1981

Operation of Protective Devices

The facility and system protective functions were successfully checked throughout the complete Phase V test program.

A summary of the no load, load and overload tests are given in Table I. The oil pressure drop during all tests across the Power Hybrid Section was approximately 4.0 PSI.

TABLE I

Load (KVA)/ Gen. Speed (RPM)	Power Factor (Lagging)	Test Start					Test Finish						Calculated PHS Total Losses - Watts	Test Paragraph Number
		Start Time	PHS Oil In Temp. (°C)	PHS Oil Out Temp. (°C)	PHS Highest Temp. (#/°C)	PHS Lowest Temp. (#/°C)	End Time	PHS Oil In Temp. (°C)	PHS Oil Out Temp. (°C)	PHS Highest Temp. (#/°C)	PHS Lowest Temp. (#/°C)			
0/11700	--	8/20/81 1022:11	66.0	66.2	6/70.6	2/67.0	1051:40	65.6	66.7	6/74.4	2/69.2		910	5.2.6.1.1.4
0/19655	--	1052:55	65.7	66.6	6/74.2	2/69.0	1059:59	65.1	66.0	6/74.3	1/68.4		744	5.2.6.1.1.5
0/24055	--	1100:59	65.2	66.6	6/77.5	1/70.2	1109:10	66.5	67.8	6/77.5	1/71.2		1075	5.2.6.1.1.6
15/11806	1.0	1525:03	65.0	65.8	6/73.8	2/68.4	1531:15	65.6	66.5	6/74.6	2/69.6		744	5.2.7.1.4
15/19730	1.0	1531:15	65.4	66.4	6/75.3	2/69.6	1535:23	65.7	66.7	6/75.3	2/69.7		827	5.2.7.1.5
15/24000	1.0	1536:37	65.7	66.8	6/75.4	2/69.7	1546:42	67.1	68.6	6/80.5	1/72.9		1241	5.2.7.1.6
15/11800	0.9	1546:57	66.8	67.8	6/75.0	2/69.9	1551:51	65.6	66.6	6/73.7	2/68.6		827	5.2.7.1.7
15/19700	0.9	1553:05	65.5	66.4	6/73.5	2/68.5	1558:58	64.7	65.5	6/71.9	2/67.5		662	5.2.7.1.7
15/24022	0.9	1601:02	64.7	65.7	6/74.4	1/68.4	1607:14	65.3	66.4	6/75.4	1/69.4		910	5.2.7.1.7
15/11800	0.75	1607:29	65.3	66.4	6/75.4	1/69.4	1613:22	64.7	65.5	6/71.8	2/67.3		662	5.2.7.1.7
15/19730	0.75	1613:37	64.7	65.5	6/71.8	2/67.3	1619:22	63.8	64.5	6/69.3	2/65.8		579	5.2.7.1.7
15/23984	0.75	1619:37	63.8	64.6	6/70.9	1/66.7	1627:22	64.3	65.2	6/72.3	1/67.1		744	5.2.7.1.7
30/11800	1.0	1846:07	63.3	64.3	6/71.7	2/66.5	1857:41	65.6	66.7	6/75.6	2/69.6		910	5.2.7.2.4

TABLE I (Continued)

			Test Start				Test Finish							
Load (KVA)/ Gen. Speed (RPM)	Power Factor (Lagging)	Start Time	PHS Oil In Temp. (°C)	PHS Oil Out Temp. (°C)	PHS Highest Temp. (#/°C)	PHS Lowest Temp. (#/°C)	End Time	PHS Oil In Temp. (°C)	PHS Oil Out Temp. (°C)	PHS Highest Temp. (#/°C)	PHS Lowest Temp. (#/°C)		Calculated PHS Total Losses - Watts	Test Paragraph Number
30/19730	1.0	8/20/81 1858:42	65.6	66.9	6/77.7	2/71.0	1905:41	66.3	68.0	6/82.2	1/73.5		1406	5.2.7.2.5
30/23973	1.0	1905:57	66.8	68.5	6/83.1	1/74.0	1922:15	69.5	71.2	6/86.3	1/77.0		1406	5.2.7.2.6
30/11800	1.0	2035:11	64.7	65.8	6/74.7	2/68.9	2040:09	65.3	66.5	6/75.5	2/69.5		992	5.2.7.2.4
30/19730	1.0	2041:23	65.5	66.8	6/77.8	2/71.1	2047:20	66.1	67.5	6/78.6	2/71.8		1158	5.2.7.2.5
30/24000	1.0	2047:35	66.4	68.1	6/82.9	1/73.8	2103:31	69.9	71.8	6/87.0	1/77.5		1571	5.2.7.2.6
30/11800	0.9	2104:11	69.9	71.1	6/79.7	2/74.1	2119:40	64.8	65.8	6/73.0	2/68.0		827	5.2.7.2.7
30/19738	0.9	2120:54	64.6	65.1	6/73.1	2/68.1	2126:51	64.4	65.3	6/72.9	1/67.9		744	5.2.7.2.7
30/24000	0.9	2127:06	64.6	65.7	6/75.5	1/69.2	2133:03	65.3	66.5	6/76.4	1/69.9		992	5.2.7.2.7
30/11800	0.75	2133:18	65.2	66.1	6/72.4	2/67.8	2141:19	64.2	65.0	6/70.9	2/66.7		662	5.2.7.2.8
30/19730	0.75	2143:23	63.9	64.6	6/70.3	2/66.1	2148:23	63.6	64.1	6/69.7	2/65.8		414	5.2.7.2.8
30/23900	0.75	2149:23	63.5	64.3	6/70.2	2/65.9	2155:38	63.9	64.7	6/71.8	2/67.1		662	5.2.7.2.8
60/11800	1.0	9/15/81 837:25	65.3	66.7	6/78.8	1/71.5	903:01	71.7	73.3	6/85.5	1/77.8		1323	5.2.7.3.5
60/19700	1.0	1802:07	63.4	65.5	6/82.9	1/72.7	1815:17	68.5	70.9	6/89.1	1/78.5		1985	5.2.7.3.6

TABLE I (Continued)

		Test Start					Test Finish							
Load (KVA)/ Gen. Speed (RPM)	Power Factor (Lagging)	Start Time	PHS Oil In Temp. (°C)	PHS Oil Out Temp. (°C)	PHS Highest Temp. (#/°C)	PHS Lowest Temp. (#/°C)	End Time	PHS Oil In Temp. (#/°C)	PHS Oil Out Temp. (#/°C)	PHS Highest Temp. (#/°C)	PHS Lowest Temp. (#/°C)		Calculated PHS Total Losses - Watts	Test Paragraph Number
60/23952	1.0	9/15/81 1817:17	68.5	71.3	6/94.0	1/81.3	1829:02	74.1	77.4	6/102.9	1/88.5		2233	5.2.7.3.7
60/12162	0.9	9/16/81 1436.47	65.3	67.2	6/76.9	1/71.9	1450:04	62.4	63.9	6/73.9	1/67.7		1241	5.2.7.3.8
60/19612	0.9	1450:14	62.4	64.2	6/77.5	1/69.8	1459:06	63.8	65.7	6/79.7	1/71.3		1571	5.2.7.3.8
60/24019	0.9	1500:06	64.0	66.3	6/84.3	1/73.7	1507:10	65.2	67.8	6/86.4	1/75.3		1985	5.2.7.3.8
60/11800	0.75	1508:10	65.3	67.7	6/86.5	1/75.3	1518:16	62.1	63.3	6/71.7	1/66.5		992	5.2.7.3.9
60/19727	0.75	1518:26	62.1	63.5	6/74.5	1/67.9	1526:23	62.9	64.4	6/75.6	1/68.7		1241	5.2.7.3.9
60/24030	0.75	1526:33	63.1	65.0	6/79.6	1/71.0	1535:27	64.6	66.6	6/81.5	1/72.6		1654	5.2.7.3.9
90/11800	0.75	10/6/81 1338:06	64.3	65.9	6/78.4	1/70.4	1345:20	65.0	66.9	6/81.3	2/72.6		1571	5.3.8.1.5
90/19700	0.75	12/2/81 906:07	63.3	65.4	6/?	1/72.6	921:12	67.8	70.3	6/89	1/78.2		1985	5.2.8.2.5
90/24024	0.75	925:12	67.1	69.9	6/?	1/79.8	932:56	70.4	73.6	6/97.6	1/83.3		2646	5.2.8.3.5

APPENDIX F
LIQUID COOLED VARIABLE SPEED CONSTANT FREQUENCY (VSCF) CONVERTER DEVICE DEVELOPMENT

Performance Test Procedure

Liquid Cooled Variable Speed
Constant Frequency (VSCF)
Converter Device Development

for

USAF
Air Force Systems Command
Aeronautical Systems Division
Wright Patterson AFB

Performance Test Procedure

CONTRACT:	F33615-78-C-2029
PROCUREMENT SPECIFICATION:	F33615-78-C-2029
CDRL: ITEM:	0002, Sequence No. 10, Revision 1
PURCHASE ORDER:	FY1455-78-00091 and Amend 01

PREPARED BY:

J. W. Butler
Project Engineer

APPROVED BY:

C. F. Triebel, Manager
Static Power & Control Engrg.

1.0 OBJECTIVE AND SUCCESS CRITERIA

1.1 OBJECTIVES

This test work description defines the detailed Performance Test procedures which are required to assure that the quality assurance provision of Par. 4 of MIL-E-23001B (modified by MIL-E-23001/POP-2) as applicable to the breadboard VSCF systems have been considered and to assure that the system meets the requirement of the contract.

Program administrative data is as follows:

Contract: F33615-78-C-2029

P.O. No.: FY1455-78-00091 & Amend 01

Supplier: General Electric Company

Supplier DOD Code No. - 89954

1.2 SUCCESS CRITERIA

The success of the test will be determined by physical examination of the power hybrids, by measuring the parameters required in the test procedure, Section 5.0 herein, and verifying that those measurements are within the performance requirements of this document. Specific success criteria will be listed under the applicable test of Section 5.0.

2.0 DESCRIPTION OF TEST ITEMS

The (VSCF test system) consists of four assemblies as follows:

Name		Part Number
A.	Generator Unit (GU)	2CM431A1X
B.	Converter Unit (CU) (Less Power Hybrid)	936E160G1
C.	Current Transformer Assembly (CTA)	3S2060DT105
D.	Power Hybrid Section (PHS)	936E174G1

1. The "GU" is an existing 2CM431 modified to electrically simulate a permanent magnet machine.
2. The "CU" is a breadboard VSCF system less the power hybrid section, capable of supplying 60KVA, 115/200 VAC three phase 400 Hz power when operated with the "GU".
3. The "CTA" contains three single phase current transformers which are used in conjunction with the "CU" to provide feeder fault protection.
4. The "PHS" contains the Power Hybrid Modules (PHM), driver circuits and heat exchanger.

3.0 DATA REQUIREMENTS

3.1 DATA RECORDING

All data required by Section 5.0 will be recorded permanently and will include the standard VSCF system measurements as follows: Each measurement includes date, time, test name, name of person conducting test and recording data and elapsed time indicator reading.

L-L/L-N voltages per phase

Line currents per phase

Power/Phase

Load KVA and power factor

Harmonic Content, DC Content, Amplitude Modulation/Phase

Output frequency, generator voltage and current

Torque and PMG frequency

Generator oil flow rate

Generator oil pressure in

Generator oil pressure out

Generator vibration

Converter air temperature in (ambient)

Power hybrid section oil in pressure

Power hybrid section oil out pressure

Power hybrid section oil in temperature

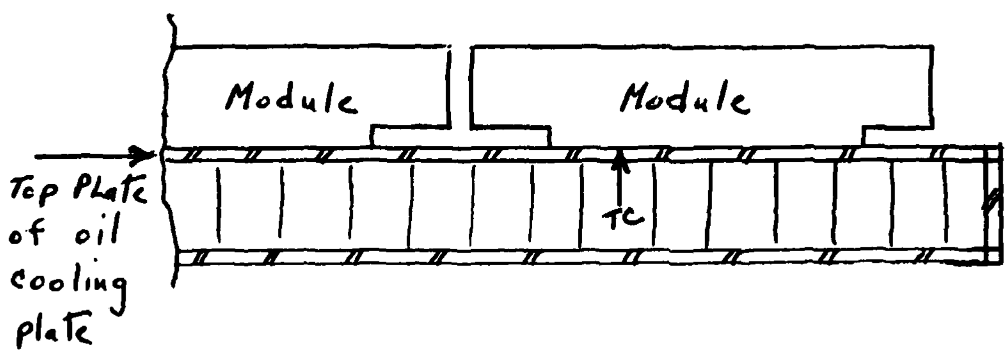
Power hybrid section oil out temperature

Power hybrid section interface* temperature at input end

Power hybrid section interface* temperature at center

Power hybrid section interface* temperature at output end

*Note: Interface will be measured by a thermocouple at the SCR location in the module and at the module mounting surface.



3.2 TEST FAILURE REPORT

This report will be initiated by the test personnel for each malfunction. All pertinent information evident at the time of malfunction will be included in the failure report.

3.3 COMPONENT FAILURE ANALYSIS REPORT

This report will be initiated by Engineering when a specific failure has been verified to be caused by (or within) the Hybrid Power Module. It will be completed by the group responsible for making a detailed failure analysis. When complete, it will identify tests performed to determine cause of failure, analysis, results of analysis and recommendations for corrective action to prevent re-occurence.

3.4 TEST SET UP

Photographs will be taken of the test set up showing the system set up during each test.

4.0 TEST PHASING, SCHEDULING AND DURATION

4.1 TEST PHASING

The power hybrid modules shall, as a minimum, have successfully completed the tests as defined in Table I, Section F of the subject contract prior to testing per this procedure.

4.2 TEST SCHEDULE/DURATION

This test is scheduled to start on October 1, 1980 and be completed by April 1, 1981.

5.0 TEST APPROACH/PROCEDURE

5.1 TEST APPROACH

Unless specified otherwise, the following general requirements will apply to all section 5.2 procedures as defined herein.

5.1.1 ENVIRONMENTAL

Unless specified otherwise, the tests will be conducted with the environmental conditions as follows:

Pressure	-	$9.624 {}^{+0.67}_{-1.01}$ Newton's/CM^2
Temperature	-	$23 \pm 10^{\circ}C$
Humidity	-	$50 \pm 30\%$

5.1.2 TEST SET UP

5.1.2.1 Test Installation

The GU will be mated to a drive stand gearbox interface and installed in its normal position on a drive stand. The CTA will be mounted in its normal position near the MLC.* MIL-L-7808 oil will be used for all tests.

5.1.2.2 Inter-Connection

Connection for testing shall be per the system configuration diagram 143D5893.

5.1.3 TEST CONDITIONS

Unless otherwise specified, each test shall be conducted under the conditions listed in this paragraph.

* Main Line Contactor

5.1.3.1 Mounting

The rotational axis of the generator package shall be horizontal. All other components shall be mounted in a horizontal position with base down.

5.1.3.2 Test Sample

Tests are to be conducted on a complete single channel. The single channel shall consist of GU, CU, HPS, and CTA as shown in 143D5893.

5.1.3.3 Voltage Measurement

Whenever voltage measurements are required, line-to-neutral voltages and line-to-line voltages shall be measured at the point of regulation and recorded. Voltage measurements shall be true rms.

5.1.3.4 Operating Conditions.

Rated channel output voltage shall be as specified in Table 1. Rated current shall be based on rated Channel KVA and 115 volts rms line-to-neutral at the point of regulation. When power factor is specified for a test, the power factor of loads on each phase shall be within 0.72 to 0.78, 0.87 to 0.93 or 0.95 to 1.0 lagging as applicable. Specified temperatures on all PHS components are to be allowed to stabilize for each load applied during each test. The temperature shall be considered to have stabilized when the temperature rise at the points or each component monitored are changing no more than 1°C during a period of 5 minutes.

5.1.3.5 Manual/System Control

During the course of the test, the system will be manually controlled by the use of a two position toggle switch.

5.1.3.6 Oil System

During the course of the test, the inlet oil temperature to the power hybrid section will be adjusted between -55°C and +80°C as required.

a. Oil Flow - Oil flow will be controlled and adjusted as required. Temperature, pressure and flow shall be monitored at both the inlet and outlet of the power hybrid section.

b. Oil temperature and pressure measurements will be monitored continually throughout the test.

5.1.3.7 Direction of Rotation

The direction of rotor rotation will be counter clockwise when viewed from the drive end.

5.2 TEST PROCEDURES

One laboratory breadboard including 18 hybrid power modules, a generator and interfacing cables will be examined and tested per this section. Quantity 9 spare hybrid power modules will be available if needed.

5.2.1 MAXIMUM WEIGHT

Verify by inspection or analysis that the maximum generator weight does not exceed 150 pounds.

5.2.2 WEIGHT

Verify by inspection or analysis that the total converter weight dry is less than 150 pounds.

5.2.3 PROOF PRESSURE

Apply pressure with both room temperature and hot oil to both oil systems in turn using proof pressure test fixture. Use TBD for generator and 258.6 N/CM^2 for hybrid power section cooling loop. Hold for 5 minutes and determine by inspection of pressure gauge that there are no major leaks in the systems. No damage, distortion or external leakage shall have been permitted during the test.

5.2.4 DIELECTRIC (GENERATOR ONLY) (4.5.3 of MIL-23001B(AS))

5.2.4.1 Electrically disconnect the generator from the frequency converter package as follows:

a. Disconnect circuits 1,2,3,4,5, and 6 from the converter input.

b. Disconnect circuits from converter to generator exciter field.

c. Disconnect circuits from converter to generator PMG.

5.2.4.2 Dielectric Check

Hi-pot test all stator windings to ground and between all windings at 750 volts AC RMS for one minute.

WARNING

HIGH VOLTAGE TEST MAY CAUSE SERIOUS OR FATAL INJURY FROM ELECTRICAL SHOCK. AVOID MAKING BODY CONTACT WITH TEST PROBES OR THE GENERATOR TEST POINTS!!!

5.2.5 OPERATION OF PROTECTION DEVICES

5.2.5.1 Facility Protective Interlocks

Determine that all facility protective interlocks are functioning or will function properly. These include:

Generator overspeed

Generator loss of oil pressure

Generator overtemperature

Generator excessive vibration

5.2.5.2 VSCF System Protection Circuits

Determine that system protective circuits are connected properly and will function as intended in the event of a fault. These include:

Loss of air flow (by thermal SW in converter)

Power hybrid section oil pressure loss

Power hybrid section overtemperature (by thermal SW on power module cooling plate)

5.2.6 NO LOAD TEST

The following tests will be performed based on the power hybrid section of converter reaching its continuous operating temperature which is defined as when the temperature rise for all of the internal thermocouples is no more than $1^{o}C$ in a five minute period. Point of regulation is at the converter output terminals. Maintain the inlet oil temperature to the generator at a safe operating value for the test conditions. Enclose power hybrid section with insulation to minimize convection/radiation heat loss.

Install the generator on the drivestand adapter.

Connect the CTA and converter into the test setup per system configuration diagram 143D5893.

5.2.6.1 <u>Heating</u>

5.2.6.1.1.1 Place the system CONTROL switch to the "NORM" position.

5.2.6.1.1.2 Adjust the hybrid power section oil system to obtain an oil inlet temperature of $65^{o} \pm 3^{o}C$ and an oil flow of TBD gpm.

5.2.6.1.1.3 Adjust the drive stand to obtain 11,800 RPM.

5.2.6.1.1.4 With no load on the system, record the system data, and thermocouple readings at least every five minutes. (See paragraph 3.1)

5.2.6.1.1.5 Increase drive stand speed to 19,730 RPM and repeat paragraph 5.2.6.1.1.4.

5.2.6.1.1.6 Increase drive stand speed to 24,000 RPM and repeat paragraph 5.2.6.1.1.4.

5.2.7 LOAD TESTS

5.2.7.1 15KVA Load

5.2.7.1.1 Place the system CONTROL switch to the "NORM" position.

5.2.7.1.2 Adjust the power hybrid section oil system to obtain an oil inlet temperature of $65^{o}C \pm 3^{o}C$ and an oil flow of TBD gpm.

5.2.7.1.3 Adjust the drive stand to obtain 11,800 RPM.

5.2.7.1.4 Apply a three-phase balanced load of 15 KVA at 1.0 power factor. Record system data and thermocouple readings at least every five minutes. (See Paragraph 3.1). Continue operating the system until stabilized temperatures are reached.

5.2.7.1.5 Increase drive stand speed to 19,730 RPM and repeat paragraph 5.2.7.1.4.

5.2.7.1.6 Increase drive stand speed to 24,000 RPM and repeat paragraph 5.2.7.1.4.

5.2.7.1.7 Decrease drivestand speed to 11,800 RPM and change load to 15 KVA at 0.9 power factor lagging. Repeat paragraphs 5.2.7.1.4 through 5.2.7.1.6.

5.2.7.1.8 Decrease drivestand speed to 11,800 RPM and change load to 15 KVA at 0.75 power factor lagging. Repeat paragraphs 5.2.7.1.4 through 5.2.7.1.6.

5.2.7.2 <u>30 KVA Load</u>

5.2.7.2.1 Place the system CONTROL switch to the "NORM" position.

5.2.7.2.2 Adjust the power hybrid section oil system to obtain an oil inlet temperature of $65^{o} \pm 3^{o}C$ and an oil flow of <u>TBD</u> gpm.

5.2.7.2.3 Adjust the drive stand to obtain 11,800 RPM.

5.2.7.2.4 Apply a three phase balanced load of 30 KVA at 1.00 power factor. Record system data and thermocouple readings at least every five minutes. (See Paragraph 3.1). Continue operating the system until stabilized temperatures are reached.

5.2.7.2.5 Increase drive stand speed to 19,730 RPM and repeat paragraph 5.2.7.2.4.

5.2.7.2.6 Increase drive stand speed to 24,000 RPM and repeat paragraph 5.2.7.2.4.

5.2.7.2.7 Decrease drive stand speed to 11,800 RPM and change load to 30KVA @ 0.9 power factor lagging. Repeat paragraphs 5.2.7.2.4 through 5.2.7.2.6.

5.2.7.2.8 Decrease drive stand speed to 11,800 RPM and change load to 30KVA @ 0.75 power factor lagging. Repeat paragraphs 5.2.7.2.4 through 5.2.7.2.6.

5.2.7.3 <u>60 KVA Load</u>

5.2.7.3.1 Place the system CONTROL switch to the "NORM" position.

5.2.7.3.2 Adjust the power hybrid section oil system to obtain an oil inlet temperature of $65^{o} \pm 3^{o}C$ and an oil flow of <u>TBD</u> gpm.

5.2.7.3.3 Adjust the drive stand to obtain 11,800 RPM.

5.2.7.3.4 With no load on the system, record the data.

5.2.7.3.5 Apply a three phase balanced load of 60 KVA at 1.00 power factor. Record system data and thermocouple readings at least every five minutes. (See Paragraph 3.1). Continue operating the system until stabilized temperatures are reached.

5.2.7.3.6 Increase drivestand speed to 19,730 RPM and repeat paragraph 5.2.7.3.5.

5.2.7.3.7 Increase drivestand speed to 24,000 RPM and repeat paragraph 5.2.7.3.5.

5.2.7.3.8 Decrease drivestand speed to 11,800 RPM and change load to 60 KVA at 0.9 power factor lagging. Repeat paragraph 5.2.7.3.5 through 5.2.7.3.7.

5.2.7.3.9 Decrease drivestand speed to 11,800 RPM and change load to 60 KVA at 0.75 power factor lagging. Repeat Paragraph 5.2.7.3.5 through 5.2.7.3.7.

5.2.8 OVERLOAD (MIL-E-23001B9AS))

5.2.8.1 90/120 KVA - 11,800 RPM

5.2.8.1.1 Place the system CONTROL switch to the "NORM" position.

5.2.8.1.2 Adjust the oil system to obtain an oil inlet temperature of 65 $\pm$ 3°C and an oil flow of TBD gpm.

5.2.8.1.3 Adjust the drive stand to obtain 11,800 RPM.

5.2.8.1.4 Apply a three phase balanced load of 60 KVA at the power factor which gave the highest operating temperature as found in 5.2.7.2. Record the system data and thermocouple readings at least every five minutes until the continuous operating temperature is reached (should take as long as the time measured before). When this point is reached, record the data as required (see para. 3.1).

5.2.8.1.5 Now increase the load to 90 KVA at 0.75 lagging power factor and operate the system for five more minutes. Record the system data and thermocouples in one minute intervals.

5.2.8.1.6 At the end of the five minute period, increase the load to 120 KVA at 0.75 lagging power factor and operate for five more seconds while continuing to record the thermocouples. Record the data as required (see para. 3.1).

5.2.8.1.7 Return the load to 60 KVA at the power factor used in 5.2.8.1.4, and operate the system until the continuous operating temperature is reached. (Continue recording the thermocouples).

5.2.8.2 <u>90/120 KVA - 19,730 RPM</u>

5.2.8.2.1 Place the system CONTROL switch to the "NORM" position.

5.2.8.2.2 Adjust the oil system to obtain an oil inlet temperature of $65^{\circ} \pm 3^{\circ}C$ and an oil flow of TBD gpm.

5.2.8.2.3 Adjust the drive stand to obtain 19,730 RPM.

5.2.8.2.4 Apply a three phase balanced load of 60 KVA at the power factor which gave the highest operating temperature as found in 5.2.7.2. Record system data and the thermocouple readings at least every five minutes until the continuous operating temperature is reached (should take as long as the time measured before). When this point is reached, record the data as required (see para. 3.1).

5.2.8.2.5 Now increase the load to 90 KVA at 0.75 lagging, power factor and operate the system for five more minutes. Record the system data and thermocouples in at least one minute intervals. Record the data as required (see paragraph 3.1).

5.2.8.2.6 At the end of the five minute period, increase the load to 120 KVA at 0.75 lagging power factor and operate the system for five more seconds while continuing to record the thermocouples. Record the data as required (See paragraph 3.1).

5.2.8.2.7 Now return the load to 60 KVA at the power factor used in 5.2.8.2.4 and operate the system until the continuous operating temperature is reached. Continue recording the thermocouples.

5.2.8.3 <u>90/120 KVA - 24,000 RPM</u>

5.2.8.3.1 Place the system CONTROL switch to the "NORM" position.

5.2.8.3.2 Adjust the oil system to obtain an oil inlet temperature of $65^{o} \pm 3^{o}C$ and an oil flow of __TBD__ gpm.

5.2.8.3.3 Adjust the drive stand to obtain 24,000 RPM.

5.2.8.3.4 Apply a three phase balanced load of 60 KVA at the power factor which gave the highest operating temperature as found in 5.2.7.3. Record system data and the thermocouple readings at least every five minutes until the continuous operating temperature is reached (should take as long as the time

measured before). When this point is reached, record the data as required. (See Paragraph # 3.1.)

5.2.8.3.5 Now increase the load to 90 KVA at 0.75 lagging power factor and operate the system for five more minutes. Record the system data and thermocouples in at least one minute intervals. Record the data as required. (See Paragraph # 3.1.)

5.2.8.3.6 At the end of the five minute period, increase the load to 120 KVA at 0.75 lagging power factor and operate the system for five more seconds while continuing to record the thermocouples. Record the data as required. (See Paragraph # 3.1).

5.2.8.3.7 Now return the load to 60 KVA at the power factor used in 5.2.8.3.4 and operate the system until the continuous operating temperature is reached. Continue recording the thermocouples.

5.2.9 SHORT CIRCUIT CAPACITY (4.5.4 of MIL-E-23001B(AS))

5.2.9.1 60 KVA/Short Circuit - 11,800 RPM

5.2.9.1.1 Place the system control switch to the "NORM" position.

5.2.9.1.2 Adjust the oil system to obtain an oil inlet temperature of $65 \pm 3^{\circ}$ C and an oil flow of TBD gpm.

5.2.9.1.3 Adjust the drive stand to obtain 11,800 RPM and verify system operation.

5.2.9.1.4 Apply a three phase balanced load of 60 KVA at the power factor which gave the highest operating temperature

as found in 5.2.7.3 . Operate the system until that stabilized temperature is reached. Record the data as required. (See Paragraph # 3.1).

5.2.9.1.5 Apply a phase "A" to neutral short circuit for 5 seconds and measure the system data and thermocouples. Remove the short circuit. Continue to record thermocouple temperatures as required.

5.2.9.1.6 Repeat Paragraph # 5.2.9.1.4.

5.2.9.1.7 Apply a phase "A" to phase "B" to neutral short circuit for 5 seconds and measure the data as required. Remove the short circuit. Continue to record temperatures as required.

5.2.9.1.8 Repeat Paragraph # 5.2.9.1.4.

5.2.9.1.9 Apply a phase "A" to phase "B" to phase "C" to neutral short circuit for 5 seconds and measure the data. Remove the short circuit. Continue to record temperatures as required.

5.2.9.1.10 Repeat Paragraph # 5.2.9.1.4.

5.2.9.1.11 Apply a phase "B" to phase "C" short circuit for 5 seconds and measure the data. Remove the short circuit. Continue to record temperatures as required.

5.2.9.1.12 Repeat Paragraph # 5.2.9.1.4.

5.2.9.1.13 Apply a phase "A" to phase "B" to phase "C" short circuit for 5 seconds and measure the data. Remove

the short circuit. Continue to record temperatures as required.

5.2.9.2 60 KVA/Short Circuit - 19,730 RPM

5.2.9.2.1 Repeat Paragraphs 5.2.9.1.1 through 5.2.9.1.13, except adjust drivestand speed to 19,730 RPM.

5.2.9.3 60 KVA/Short Circuit - 24,000 RPM

Repeat Paragraphs 5.2.9.1.1 through 5.2.9.1.13, except adjust drivestand speed to 24,000 RPM.

5.2.10 PERFORMANCE AND ENDURANCE

5.2.10.1 Reference - Paragraph 4.5.14, MIL-E-23001B (AS) modified by MIL-E-23000/POP-2.

5.2.10.2 Requirement - The "PHS" shall operate failure-free for a minimum time of 200 hours during this test. Time shall be accummulated by completing 10 of the cycles shown below for room ambient operation plus 3 of the temperature cycles shown in Figure 4 of MIL-STD-781B. The channel shall be shut down, generator not turning, for a minimum of 4 hours after each 5 cycles of operation. The shut down time shall not be considered as test time.

Three temperature cycles, Figure 4 of MIL-STD-781B with A = B = 4 hours, a high temperature of 80° C and a low temperature of -55° C shall be accomplished on the channel completing 10 cycles of room ambient operation. The channel shall be operated at no load throughout the heating portion of the temperature cycle with the temperature cycling done on only the

power hybrid section.

Room Ambient Operation

Generator Input Speed	% Load On System	Operating Time (Hrs.)
Min. (11,800)	0	1
Min.	25	1
Min.	100	1
Max. (24,000)	100	2
Normal (19,730)	100	2
Normal	50	4
Max.	50	2
Normal	100	2
Min.	50	1

The following overload and fault conditions shall be imposed and shall be considered as test time. These tests shall be distributed over the whole testing period.

a. 200% load at 0.75 power factor for a duration of five seconds, 5 times.

b. 150% load at 0.75 power factor for a duration of five minutes, 5 times.

c. Single phase and two phase line-to-line-to-neutral short circuits shall be repeated 3 times for a minimum of five seconds for each of the generator input speed conditions.

5.2.10.3 Set-up

Install the generator on the drive stand adapter. Connect the CTA and converter into the test set up per Paragraph 5.1.2.2. Place the hybrid power section in a temperature chamber capable of -55° C to 80° C ambient. Maintain the generator inlet oil at approximately 30°C.

5.2.10.4 Room Ambient Operation

5.2.10.4.1 Place the system control switch to the "NORM" position.

5.2.10.4.2 Adjust the hybrid power section oil system to obtain an oil inlet temperature of 65 $\pm$ 3°C and an oil flow of TBD gpm.

5.2.10.4.3 Adjust the drive stand to obtain 11,800 RPM.

5.2.10.4.4 With no load on system operate for 1 hour. Record the data per Paragraph 3.1.

5.2.10.4.5 Apply a three phase balanced load of 15 KVA at 0.75 lagging power factor. Operate system for 1 hour and record data.

5.2.10.4.6 Increase the balanced three phase load to 60 KVA at 0.75 lagging power factor. Operate for 1 hour and record data.

5.2.10.4.7 Increase drive stand speed to 24,000 RPM and operate at 60 KVA load for 2 hours. Record data.

5.2.10.4.8 Reduce drive stand speed to 19,730 RPM and operate at 60 KVA load for 2 hours. Record data.

5.2.10.4.9 Reduce load to 30 KVA at 0.75 lagging power factor. Operate for 4 hours and record data.

5.2.10.4.10 Increase drive stand speed to 24,000 RPM and operate at 30 KVA at 0.75 lagging power factor for 2 hours. Record data.

5.2.10.4.11 Reduce drive stand speed to 19,730 RPM and increase load to 60 KVA at 0.75 lagging power factor for 2 hours. Record data.

5.2.10.4.12 Decrease drive stand speed to 11,800 RPM and load to 30 KVA at 0.75 lagging power factor and operate for 1 hour. Record data.

5.2.10.4.13 Repeat paragraphs 5.2.10.4.3 through 5.2.10.4.12. four more times.

5.2.10.4.14 Shut system down with generator not turning for a minimum of 4 hours. The shut down time shall not be considered as test time.

5.2.10.4.15 Repeat paragraphs 5.2.10.4.2 through 5.2.10.4.13 once again.

5.2.10.5 Temperature Cycling (See Figure 1)

5.2.10.5.1 hut system down with generator not turning and stabilize power hybrid section in ambient of -55° C.

5.2.10.5.2 Set drive stand speed to 19,730 RPM and system on at no load condition. Record data per Paragraph 3.1.

5.2.10.5.3 Gradually increase hybrid power section inlet oil temperature to 80° C over a 4-hour period.

5.2.10.5.4 Operate system for an additional 4 hours with inlet oil temperature maintained at 80° C.

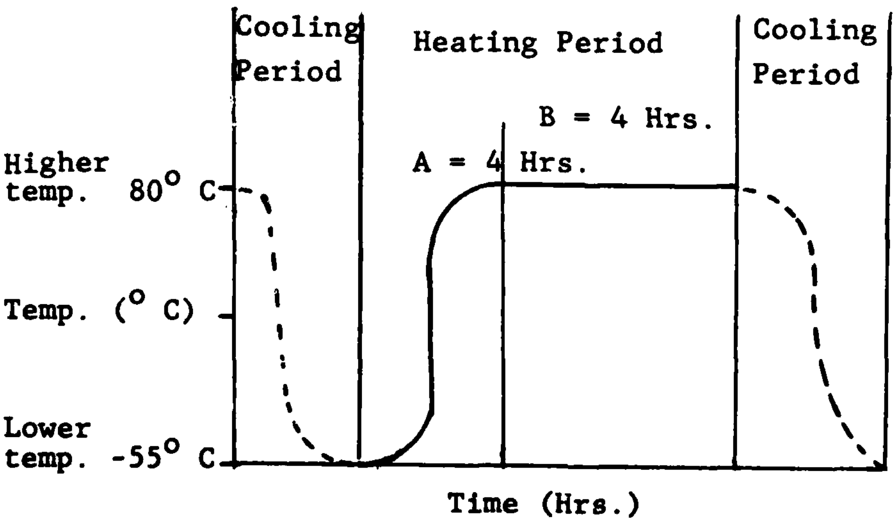


Figure 1

TEMPERATURE-TIME PROFILE FOR STANDARD TEMPERATURE CYCLING

------------ Equipment off

____________ Equipment operated at no load

A. Time for equipment to stabilize at higher temperature

B. Time of stabilized equipment operation at higher temperature

5.2.10.5.5 Repeat Paragraphs 5.2.10.5.1 through 5.2.10.5.4 two more times accummulating a minumum of "system on" operating time of 20 hours.

5.2.10.5.6 Shut system down completely.

TABLE I

TEST LIMITS

LOAD	VOLTAGE	FREQUENCY
Up to 60 KVA	113.5 - 116.5	396 - 404
60 KVA to 90 KVA	113.0 - 116.5	396 - 404
90 KVA to 120 KVA	112.5 - 116.5	396 - 404

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